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Particle Physics Division
Mechanical Department

LAPD Tank Low Pressure Vessel Engineering Note

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Preparation date: 9.2.2011

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Signature: Jay C Theilacker

Of Division / Section AD **Date:** 9/6/11

Fermilab ES&H Chapter 5031.5 compliance certification

Accepted by: Michael Lindgren
(Print Name)

Signature: [signature]

Of Division / Section PPD **Date:** 9/12/2011

CONTENTS

I. DESCRIPTION

II. FESHM 5031.5 compliance

III. TA5031.5 Form

IV. Design Calculations

- A. Vendor initial calculations
- B. Vendor revised calculations
- C. Tank support calculations
- D. Anchor bolt calculations
- E. FEA model of empty tank internal pressure test
- F. FEA model of relief valve nozzle load on tank nozzle
- G. FEA model of empty tank external pressure test

V. Relief valve sizing

- A. Sizing summary
- B. Internal pressure relief pressure drop
- C. External pressure relief pressure drop
- D. Tyco relief valve data sheet

VI. Tank Drawings

- A. Midwest Imperial Steel Fabricators
- B. Fermilab insulation and support

VII. Fabrication

- A. Material Certificates
- B. Welding qualifications
- C. Nameplate photograph
- D. API compliance certification

VIII. Testing

- A. General inspection
- B. Radiography
- C. Full hydrotest
- D. Empty pneumatic test – internal pressure
- E. Empty pneumatic test – external pressure

IX. Tank filling procedure

I. Description

The LAPD tank is an industrial low pressure storage tank. The tank is flat bottom with a dished top. The tank will contain liquid argon.

There is no directly applicable code covering the LAPD tank. API 620 (2002), appendix Q was used as the design and fabrication basis for the LAPD tank. The closest code was API 620 (2002), Appendix Q, "Low-Pressure Storage Tanks for Liquefied Hydrocarbon Gases". API 620, 10th edition, appendix Q was used as the design and fabrication basis for the LAPD tank.

Highlights of API 620 (2002), Appendix Q:

- Covers low-pressure flat-bottomed carbon steel storage tanks
- Vapor space design pressure of up to 15 psig
- Low pressure storage tanks for liquidized hydrocarbons down to -270 ^{o}F

II. FESHM 5031.5 compliance

The ‘Responsibilities’ section of 5031.5 lists the requirements for low pressure tanks. Compliance to the ‘responsibilities” is detailed in the following table, by FESHM 5031.5 paragraph.

Compliance to FESHM 5031.5 ‘Responsibilities’:

Paragraph	Compliance
1.	Done. The MAWP is established by Midwest Imperial Design calculations per API 620.
2.	Done. A relief valve is installed.
2.1	Done. Relief valve sizing calculations are documented
2.2	No action needed
2.3	No action needed
2.4	Capacity certified by relief valve manufacturer and set points tested at Fermilab.
2.5	Done. In vessel engineering note
2.6	Done. In vessel engineering note
3.	FESHM 5033 not applicable since PxV is less than 515
3.1	Not applicable
3.2	Done. Vacuum relief installed
4.	Set point tested and tested as installed.
5.	Will not be operated until the relief valve is installed and documentation requirements are satisfied
6.	Testing is documented in the vessel note

LOW PRESSURE VESSEL SUMMARY
FOR CHAPTER 5031.5

Prepared by: Terry Tope, Richard Schmitt, Mark Adamowski

Date: 08/23/11

THIS VESSEL CONFORMS TO FERMLAB ES&H MANUAL CHAPTER 5031.5			
Vessel Title	LAPD TANK		
Vessel Number			
Maximum Allowable Working Pressure (MAWP)			
Internal Pressure	3.0 psi at -320 F / 100 F		
External Pressure	0.2 psi at -320 F / 100 F		
Working Temperature Range	-320 ºF	+100 ºF	
Contents	Argon liquid / gas		
Designer / Manufacturer	Midwest Imperial Steel Fabricators, LLC		

Vessel Drawing #	**Location of Original**
Y08-125 sht 1 (by Midwest Imp. Steel)	DOCDB LARTPC-DOC-408
Y08-125 sht 2 (by Midwest Imp. Steel)	DOCDB LARTPC-DOC-408
ME466366 (insul. and tank support)	DOCDB LARTPC-DOC-514

Operating Procedure:
Is an operating procedure necessary for the safe operation of this vessel? Yes

Tank filling procedure is referenced in the appendix.

Additional Information:

This tank is designed to the best available standard. The closest standard is API 620. This tank does not fall within the scope of API 620. However the applicable sections of API 620 were applied in the tank's design.

List of Reliefs and Relief Settings:

Manufacturer	Model #	Set Pressure	Flow Rate	Size
Anderson Greenwood	9390C06SSTC Pilot relief valve	3 psig internal / 0.18 psig external	5,271 SCFM air @ 10% OP 1,018 SCFM air @ 0.2 psig external	6x8 inch

IV. Design Calculations

IV. A. VENDOR INITIAL CALCULATIONS

MIDWEST IMPERIAL STEEL FABRICATORS, LLC
400 S. LaGRANGE ROAD, FRANKFORT, ILLINOIS 60423

CUSTOMER
FERMI LAB
KIRK ROAD & WILSON STREET
BATAVIA, IL 60510

CUSTOMER PURCHASE ORDER
583306

DESIGN CALCULATIONS FOR

LIQUID ARGON TANK
TAG # ME-444715
120"OD x 120" SEAM / SEAM
WITH DISHED ROOF AND FLAT BOTTOM

Vessel designed with Etank 2000

M I FAB JOB No.	**Y08-125**
DESIGN CODE	API 620 10th Edition, Feb 2002
DESIGN PRESSURE	3 psi internal / 0.2 psi external
DESIGN TEMPERATURE	-320 TO 100 DEGREES F
SERIAL NUMBER	Y08-125
YEAR BUILT	2009
RADIOGRAPHY	None
POST WELD HEAT TREATMENT	None
CONSTRUCTION TYPE	Welded

SIGNATURES

APPROVED: Steven Walters DATE: 11/19/08

ETANK SETTINGS SUMMARY

To Change These ETank Settings, Go To Tools->Options, Behavior Tab.

```
-----------------------------------------------------------------------
   No 650 Appendix F Calcs when Tank P = 0  -> Default : False
   Repad 650 Design Basis
      -> Default for Tank Roof Nozzles       : Use API Default 1/4 in.
      -> This Tank                           : Use API Default 1/4 in.
   Show MAWP / MAWV Calcs                           : True
   Enforce API Minimum thicknesses                  : True
   Enforce API Maximum Roof thickness               : True
   Enforce Minimum Self Supp. Cone Pitch (2 in 12)  : True
   Force Non-Annular Btm. to Meet API-650 3.5.1     : False
   Set t.actual to t.required Values                 : False
   Maximum 650 App. S or App. M Multiplier is 1     : True
   Enforce API Maximum Nozzle Sizes                 : True
   Use Jawad External Pressure in Wind Girder Calcs : True
   Max. Self Supported Roof thickness               : 0.5 in.
   Max. Tank Corr. Allowance                        : 0.5 in.
   Shell external pressure/wind t-min includes C.A. : False
```

M I FAB - Y08-125
TANK REPORT: Printed - 11/19/2008 11:41:27 AM

SUMMARY OF DESIGN DATA and REMARKS

Job	: Y08-125
Date of Calcs.	: 11/19/2008 , 11:41 AM
Mfg. or Insp. Date	: 11/17/2008
Designer	: SCW`
Project	: FERMI LAB P.O. 583306
Tag Number	: ME-444715
Plant	: FERMI LAB
Plant Location	: FERMI LAB
Site	: FERMI LAB
Design Basis	: API-620 10th Edition, Feb 2002

- TANK NAMEPLATE INFORMATION

- Operating Ratio: 0.4
- Design Standard:
- API-620 10th Edition, Feb 2002 -
- (None) -
- Roof : A-240 Type 304: 0.1875in. -
- Shell (1 TO 3): A-240 Type 304: 0.1875in., 0.1875in. -
- Bottom : A-240 Type 304: 0.25in. -

Design Internal Pressure = 3 PSI or 83.14 IN. H2O
Design External Pressure = -0.2 PSI or -5.54 IN. H2O

MAWP = 15.0000 PSI or 415.70 IN. H2O
MAWV = -0.4162 PSI or -11.53 IN. H2O

Design Temperature = 100 Deg.F	
Seismic Zone = 1	Importance Factor = 1
Site Amplification Factor = 1.5	Basic Wind Velocity = 0 mph
Ground Snow Load = 20 lbf/ft^2	Roof Live Load = 20 lbf/ft^2
Added Roof Dead Load = 0 lbf/ft^2	
S.G. of Contents = 1.39	Tank Joint Efficiency = 0.7
OD of Tank = 10 ft	Shell Height = 10 ft
Max. Liq. Level = 10 ft	

DESIGN NOTES

NOTE 1 : Per API-650 F.7.6 - Hydro test pressure = 1.25 * P
= 3.75 PSI or 103.93 IN. H2O

M I FAB - Y08-125
TANK REPORT: Printed - 11/19/2008 11:41:27 AM

SUMMARY OF RESULTS

Shell Material Summary (Bottom is 1)

Shell #	Width (ft)	Material	Sts (psi)	Sca (psi)	Weight (lbf)
Sca = 8340 (Per 5.5.4.3) = 8,340 PSI (Allowable Compressive Stress)					
2	5	A-240 Type 304	22,500	8,340	1,260
Sca = 8340 (Per 5.5.4.3) = 8,340 PSI (Allowable Compressive Stress)					
1	5	A-240 Type 304	22,500	8,340	1,260
Total Weight					2,520

Shell API 620 Summary (Bottom is 1)

Shell #	t.int620 (in.)	t.ext620 (in.)	t.required (in.)	t.actual (in.)
2	0.0229	0.0313	0.1875	0.1875
1	0.0344	0.033	0.1875	0.1875

Self Supported Umbrella Roof; Material = A-240 Type 304

t.required = 0.062 in.
t.actual = 0.1875 in.
Roof Joint Efficiency = 0.7

Weight = 656 lbf

Bottom Type: Flat Bottom: Non-Annular
Material = A-240 Type 304
t.required = 0.25 in.
t.actual = 0.25 in.
Bottom Joint Efficiency = 0.7

Weight = 869 lbf

ANCHOR BOLTS: (8) 1in. UNC Bolts, A-193 Gr B7

```
&lt;Roof Design Per API 620&gt;

UMBRELLA ROOF:  A-240 Type 304

E  = Roof Joint Efficiency = 0.7
Lr = Entered Roof Live Load = 20 lbf/ft²
Lr_1 = Computed Roof Live Load, including External Pressure

Lr_1 = Lr + External_Pressure
     = 20 + 0.2*144 = 48.8 lbf/ft^2
Dead_Load = Snow_Load + Insulation + Weight
          = 20 + (8)(0/12) + 8.03
          = 28.0325 lbf/ft^2

Dish Radius (Rs) = 10 ft

Alpha = 60.0000 degrees  (angle between the Normal to the roof and
                 a horizontal line at the
                 roof-to-shell juncture)
Theta = 30.0000 degrees  (angle between the Normal to the roof and
                 a vertical line at the
                 roof-to-shell juncture)

Rs = R1 = R2 = 120 in.

Rc = R3 = OD/2 = 60 in.

&lt;Weight, Surface Area, and Projected Areas of Roof&gt;

   hR = Height of Roof
      = R - SQRT[R^2 - (OD/2)^2]
      = 10 - SQRT[10^2 - (10/2)^2]
      = 1.331 ft

   t_ins = Thickness of Roof Insulation
         = 0 ft
   Ap_Vert = Vertical Projected Area of Roof
           = PI*([R + t_ins]^2)(Alpha/360) - OD*([R + t_ins] - hR)/2
           = PI*(10^2)(59.9499/360) - 10*(10 - 1.331)/2
           = 8.9712 ft^2

   Horizontal Projected Area of Roof (Per API-650 3.2.1.f)

   Xw = Moment Arm of UPLIFT wind force on roof
      = 0.5*OD
      = 0.5*10
      = 5 ft
   Ap = Projected Area of roof for wind moment
      = PI*R^2
      = PI*5^2
      = 78.54 ft^2

   Roof_Area = 288*PI*R*hR
             = 288*PI*10*1.331
             = 11,762 in^2
```

```
   Weight = (Density)(t)(Roof_Area)
          = (0.2975)(0.1875)(11,762)
          = 656 lbf   (New)
          = 656 lbf   (Corroded)


< Uplift on Tank >  (based on API-650 F.1.2)

NOTE:  This flat bottom tank is assumed supported by the bottom plate.
  If tank not supported by a flat bottom, then uplift calculations
  will be N.A., and for reference only.

   For flat bottom tank with self supported roof,
   Net_Uplift = Uplift due to design pressure less
                Corroded weight of shell and roof plates.

      = P * PI / 4 * D ^ 2 * 144 «
        - Corr. shell - Corr. roof weight
      = 3 * 3.1416 / 4 * 100 * 144 «
        - 2,520 - 656
      = 30,753 lbf


< Uplift Case based on API-650 1.1.1 >

   P_Uplift = 33,929 lbf
   W_Roof_Plates (corroded) = 656 lbf
   W_Shell (corroded) = 2,520 lbf
   Since P_Uplift > W_Roof + W_Shell,
   Tank Roof should meet App. F.1.3 and F.7 requirements.
```

```
< API-620 >

   R3 = 60 in.

   At = PI*OD^2/4*144
      = PI*10^2/4*144
      = 11,310 in^2   (Cross-Sectional Area of Roof at Shell)

< Internal Pressure - Top-Head Edge >

   W = - (weight roof plates) = -656 lbf
   W/At = (-656 / 11,310)
        = -0.058 PSI
   W/At' = -0.0558 PSI

   P = 3 PSI or 83.14 IN. H20

   <Meridional and Latitudinal Forces>

   (At the Edge of Top Head)
   T1 = Rs/2*(P + W/At)
      = 120/2*(3 + -0.058)
      = 176.52 lbf/in
   T2 = Rs*[P + W/At*COS(Alpha)] - T1
      = 120*[3 + -0.058*COS(60.0000)] - 176.52
      = 180 lbf/in

   < API-620 >
   Minimum thickness (t) requirement:

   (Per 5.10.3.2)
   T = MAX(T1, T2) = 180 lb./in.

   Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

   t-Calc = T/(Sts*E) + CA = 180/(22,500*0.7) + 0 = 0.0114 in.

   t-Calc = 0.0114 in.

< Internal Pressure - Top-Head Center >

   P = 3 PSI or 83.14 IN. H20

   (At the Center of Top Head)
   T1' = (Rs/2)*(P + W/At)
       = (120/2)*(3 + (-0.0558)) = 176.65 lbf/in
   T2' = Rs*(P + W/At) - T1'
       = 120*(3 + (-0.0558)) - 176.65 = 176.65 lbf/in

   < API-620 >
   Minimum thickness (t) requirement:

   (Per 5.10.3.2)
   T = MAX(T1, T2) = 176.7 lb./in.

   Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

   t-Calc = T/(Sts*E) + CA = 176.7/(22,500*0.7) + 0 = 0.0112 in.
```

```
    t-Calc = 0.0112 in.

    Since t.actual > T620,
      Back-Calculating Pmax using t.actual as target, and T620 routine...
      Entry Condition: P_x = 3.001, t-620 = 0.0114
      Exit Condition: P_x = 49.23, t-620 = 0.1875

      NOTE: Tank Limited to 15 PSI  (per API-620)

      P_max_int = 15PSI, or 415.7 IN. H2O
            (limited by Roof Plate)

    P_max_int = MAX(15, 0) = 15 PSI or 415.7 IN. H2O


< External Pressure - Top-Head Edge >

    W = -(Lr + Dead_Load) * Roof_Area
      = -(20 + 28.0325) * 81.6806
      = -3,923 lbf
    W/At = (-3,923 / 11,310)
         = -0.3469 PSI
    W/At' = -0.3335 PSI

    P = PV_Entered = -0.2 PSI or -5.54 IN. H20

    <Meridional and Latitudinal Forces>

    (At the Edge of Top Head)
    T1 = Rs/2*(P + W/At)
       = 120/2*(-0.2 + -0.3469)
       = -32.81 lbf/in
    T2 = Rs*[P + W/At*COS(Alpha)] - T1
       = 120*[-0.2 + -0.3469*COS(60.0000)] - -32.81
       = -12 lbf/in

    < API-620 >
    Minimum thickness (t) requirement:

    Tp = MAX(ABS(T1),ABS(T2))
       = 32.8 lb/in.
    Tpp = MIN(ABS(T1),ABS(T2))
       = 12 lb/in.
    Rp = R2 = 120 in.
    Rpp = R1 = 120 in.

    t_18 = SQRT[(Tp + 0.8*Tpp)*Rp]/1342 + CA
         = 0.0532 in.

    t_19 = SQRT[Tpp*Rpp]/1000 + CA
         = 0.0379 in.

    (t_18 - CA)/Rp = 0.0004
    (t_19 - CA)/Rpp = 0.0003

    t-Calc = MAX(t_18,t_19)
    Sca = 10^6*(t-CA)/R  (Per 5.5.4.3)
     = 1,563 PSI  (Allowable Compressive Stress)
```

```
   t-Calc = 0.0532 in.

< External Pressure - Top-Head Center >

   P = PV_Entered = -0.2 PSI or -5.54 IN. H20

   (At the Center of Top Head)
   T1' = (Rs/2)*(P + W/At)
       = (120/2)*(-0.2 + (-0.3335)) = -32.01 lbf/in
   T2' = Rs*(P + W/At) - T1'
       = 120*(-0.2 + (-0.3335)) - -32.01 = -32.01 lbf/in

   < API-620 >
   Minimum thickness (t) requirement:

T1 & T2 Negative and Equal

   T = MAX(ABS(T1), ABS(T2)) = 32 lb./in.
Ratio < .00667

   t-Calc = SQRT[T*R/10^6] + CA
          = SQRT[(32)(120)/10^6] + 0
          = 0.062 in.

  Congruent t/R ratio results per API-620 5.5.4.3
   Sca = 10^6*(t-CA)/R  (Per 5.5.4.3)
    = 1,563 PSI  (Allowable Compressive Stress)

   t-Calc = 0.062 in.

   Since t.actual > T620,
     Back-Calculating Pmax using t-Calc as target, and T620 routine...
     Entry Condition: V_x = -0.2 PSI, t-620 = 0.062
     Exit Condition: V_x = -4.549, t-620 = 0.1875

     P_max_ext = -4.549 PSI, or -126.07 IN. H2O
           (due to Roof Plate)

   P_max_ext = -4.549 PSI or -126.07 IN. H2O


   t-Calc = MAX( 0.0114, 0.062 )
          = 0.062 in.

   t.required = 0.062 in.
```

<ToriSpherical Head Knuckle Calculations>

(Per ASME VIII DIV. 1, Appendix 1 Sect. 4)

```
L = Inside Dish Radius = 120 in.,
P = P-Design = 3 PSI,
E = Joint Efficiency = 0.7,
t = t.actual = 0.1875 in.,
r = Knuckle Radius = 7.2 in.,
and S = Material Allowable API-620 Design Stress

M = 0.25 * (3 + SQRT(L/r))
  = 0.25 * (3 + SQRT(120/7.2))
  = 1.7706 in.

t-Calc = (P*L*M)/(2*S*E - 0.2*P) + CA
       = (3*120*1.7706)/(2*22,500*0.7 - 0.2*3) + 0
       = 0.0202 in.

t.required (Knuckle) = t-Calc (Knuckle) = 0.0202 in.

P_max_int = (2*S*E*(t-ca))/(L*M + 0.2*(t-ca))
          = (2*22,500*0.7*0.1875)/(120*1.7706 + 0.2*0.1875)
          = 27.7926 PSI      (Knuckle)

P_max_int = MIN(15, P_max_int) = 15 PSI      (API-620)
```

< ROOF DESIGN SUMMARY >

```
t.required = 0.062 in.
t.actual = 0.1875 in.

P_max_internal = 15 PSI or 415.70 IN. H2O
P_max_external = -4.549 PSI or -126.07 IN. H2O
```

```
SHELL COURSE DESIGN   (Bottom Course is #1)

Course # 1
   Material: A-240 Type 304;   Width = 5 ft.
   Corrosion Allow. = 0 in.
   Joint Efficiency = 0.7

< API-620 >

   R = R2 = Rc = 60 in.
   At = 11,310 in^2

 < Internal Pressure - Full >

   W = - (roof plates + shell) = -3,180 lbf
   W/At = (-3,180 / 11,310)
        = -0.2812 PSI

   Px = P + P_liquid = 3 + 6.0187 = 9.0187 PSI

   <Meridional and Latitudinal Forces>

   T1 = Rc/2*(P + W/At)
      = 60/2*(9.0187 + -0.2812)
      = 262.13 lbf/in

   T2 = P*Rc
      = 9.0187*60
      = 541.12 lbf/in

   < API-620 >
   Minimum thickness (t) requirement:

   (Per 5.10.3.2)
   T = MAX(T1, T2) = 541.1 lb./in.

   Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

   t-Calc = T/(Sts*E) + CA = 541.1/(22,500*0.7) + 0 = 0.0344 in.

   t-Calc = 0.0344 in.

   Since t.actual > T620,
     Back-Calculating Pmax using t.actual as target, and T620 routine...
     Entry Condition: P_x = 9.0197, t-620 = 0.0344
     Exit Condition: P_x = 49.214, t-620 = 0.1875

     NOTE: Tank Limited to 15 PSI  (per API-620)


   P_shell_int = 15 PSI   (due to Shell Course, without Liquid Head)

 < External Pressure - Empty >

   Lr_shell (Total Roof Live Load weight supported by shell)
            = Ar * Lr / 144
            = 11,762 * 20 / 144
            = 1,634 LBF
```

```
    W = - (Roof Plates + Shell + Lr_shell + Dead Load)
      = - (656 + 2,524 + 1,634 + 1,634)
      = -6,448 lbf
    W/At = (-6,448 / 11,310)
         = -0.5701 PSI
    PV = -0.2 PSI

    <Meridional and Latitudinal Forces>

    T1 = Rc/2*(P + W/At)
       = 60/2*(-0.2 + -0.5701)
       = -23.1 lbf/in

    T2 = P*Rc
       = -0.2*60
       = -12 lbf/in

    < API-620 >
    Minimum thickness (t) requirement:

    Tp = MAX(ABS(T1),ABS(T2))
       = 23.1 lb/in.
    Tpp = MIN(ABS(T1),ABS(T2))
       = 12 lb/in.
    Rp = R2 = 60 in.
    Rpp = R1 = 60 in.

    t_18 = SQRT[(Tp + 0.8*Tpp)*Rp]/1342 + CA
         = 0.033 in.

    t_19 = SQRT[Tpp*Rpp]/1000 + CA
         = 0.0268 in.

    (t_18 - CA)/Rp = 0.0006
    (t_19 - CA)/Rpp = 0.0004

    t-Calc = MAX(t_18,t_19)
    Sca = 10^6*(t-CA)/R  (Per 5.5.4.3)
     = 3,125 PSI  (Allowable Compressive Stress)

    t-Calc = 0.033 in.

    Since t.actual > T620,
      Back-Calculating Pmax using t-Calc as target, and T620 routine...
      Entry Condition: V_x = -0.2 PSI, t-620 = 0.033
      Exit Condition: V_x = -12.401, t-620 = 0.1875


    P_shell_ext = -12.401 PSI (due to Shell Course)
Course # 2
    Material: A-240 Type 304;   Width = 5 ft.
    Corrosion Allow. = 0 in.
    Joint Efficiency = 0.7

< API-620 >

    R = R2 = Rc = 60 in.
    At = 11,310 in^2
```

```
< Internal Pressure - Full >

  W = - (roof plates + shell) = -1,918 lbf
  W/At = (-1,918 / 11,310)
       = -0.1696 PSI

  Px = P + P_liquid = 3 + 3.0093 = 6.0093 PSI

  <Meridional and Latitudinal Forces>

  T1 = Rc/2*(P + W/At)
     = 60/2*(6.0093 + -0.1696)
     = 175.19 lbf/in

  T2 = P*Rc
     = 6.0093*60
     = 360.56 lbf/in

  < API-620 >
  Minimum thickness (t) requirement:

  (Per 5.10.3.2)
  T = MAX(T1, T2) = 360.6 lb./in.

  Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

  t-Calc = T/(Sts*E) + CA = 360.6/(22,500*0.7) + 0 = 0.0229 in.

  t-Calc = 0.0229 in.

  Since t.actual > T620,
    Back-Calculating Pmax using t.actual as target, and T620 routine...
    Entry Condition: P_x = 6.0103, t-620 = 0.0229
    Exit Condition: P_x = 49.222, t-620 = 0.1875

    NOTE: Tank Limited to 15 PSI  (per API-620)


  P_shell_int = 15 PSI   (due to Shell Course, without Liquid Head)

< External Pressure - Empty >

  Lr_shell (Total Roof Live Load weight supported by shell)
          = Ar * Lr / 144
          = 11,762 * 20 / 144
          = 1,634 LBF

  W = - (Roof Plates + Shell + Lr_shell + Dead Load)
    = - (656 + 1,262 + 1,634 + 1,634)
    = -5,186 lbf
  W/At = (-5,186 / 11,310)
       = -0.4585 PSI
  PV = -0.2 PSI

  <Meridional and Latitudinal Forces>

  T1 = Rc/2*(P + W/At)
     = 60/2*(-0.2 + -0.4585)
     = -19.76 lbf/in
```

```
   T2 = P*Rc
      = -0.2*60
      = -12 lbf/in

   < API-620 >
   Minimum thickness (t) requirement:

   Tp = MAX(ABS(T1),ABS(T2))
      = 19.8 lb/in.
   Tpp = MIN(ABS(T1),ABS(T2))
      = 12 lb/in.
   Rp = R2 = 60 in.
   Rpp = R1 = 60 in.

   t_18 = SQRT[(Tp + 0.8*Tpp)*Rp]/1342 + CA
        = 0.0313 in.

   t_19 = SQRT[Tpp*Rpp]/1000 + CA
        = 0.0268 in.

   (t_18 - CA)/Rp = 0.0005
   (t_19 - CA)/Rpp = 0.0004

   t-Calc = MAX(t_18,t_19)
   Sca = 10^6*(t-CA)/R  (Per 5.5.4.3)
    = 3,125 PSI  (Allowable Compressive Stress)

   t-Calc = 0.0313 in.

   Since t.actual > T620,
     Back-Calculating Pmax using t-Calc as target, and T620 routine...
     Entry Condition: V_x = -0.2 PSI, t-620 = 0.0313
     Exit Condition: V_x = -12.43, t-620 = 0.1875


   P_shell_ext = -12.43 PSI (due to Shell Course)

< SHELL COURSE #1 SUMMARY >

   t_shell_min governs.  See the STIFFENING RINGS Calculations.

   t-Calc = MAX(t-Calc_620, t_shell_min)
          = MAX(0.0344, 0.0701)
          = 0.0701 in.
   t.min620 per 5.10.4.1.c = 0.1875 in.
   t.min620 per 5.10.4.1.a = 0.1875 in.

 t.required = MAX(t.design,t.min620)
            = MAX(0.0701,0.1875) = 0.1875 in.
 t.actual = 0.1875 in.

 Weight = Density*PI*[(12*OD) - t]*12*Width*t
        = 0.2975*PI*[(12*10)-0.1875]*12*5*0.1875
        = 1,260 lbf     (New)
        = 1,260 lbf     (Corroded)
```

```
< SHELL COURSE #2 SUMMARY >

   t_shell_min governs.  See the STIFFENING RINGS Calculations.

   t-Calc = MAX(t-Calc_620, t_shell_min)
          = MAX(0.0313, 0.0701)
          = 0.0701 in.
   t.min620 per 5.10.4.1.c = 0.1875 in.
   t.min620 per 5.10.4.1.a = 0.1875 in.

 t.required = MAX(t.design,t.min620)
            = MAX(0.0701,0.1875) = 0.1875 in.
 t.actual = 0.1875 in.

 Weight = Density*PI*[(12*OD) - t]*12*Width*t
        = 0.2975*PI*[(12*10)-0.1875]*12*5*0.1875
        = 1,260 lbf    (New)
        = 1,260 lbf    (Corroded)
```

FLAT BOTTOM: NON-ANNULAR PLATE DESIGN

```
   Bottom Plate Material :  A-240 Type 304
   Annular Bottom Plate Material :  A-36

<Weight of Bottom Plate>

   Bottom_Area = PI/4*(Bottom_OD)^2
               = PI/4*(122.)^2
               = 11,690 in^2

   Weight = Density * t.actual * Bottom_Area
          = 0.2975 * 0.25 * 11,690
          = 869 lbf    (New)
          = 869 lbf    (Corroded)

< API-620 >

   t_min = 0.25 + CA = 0.25 + 0 = 0.25 in. (per Section 5.9.4.2)

   t-Calc = t_min = 0.25 in.

< Vacuum Calculations >  (per ASME Section VIII Div. 1)

   Weight of Corr. Bottom Plate Resisting External Vacuum

   P_btm = 0.2975 * 0.25
         = 0.0744 PSI or 2.06 IN. H2O

   P_ext = PV + P_btm = -0.2 + 0.0744 = -0.1256 PSI or -3.48 IN. H2O
     = -0.1256 PSI

   td_ext = (t-Calc - CA)      (1st course)
          = (0.0701 - 0)
          = 0.0701 in.

   ts = (t.actual - CA)    (1st course)
      = (0.1875 - 0)
      = 0.1875 in.

   C = 0.33 * td_ext / ts
     = 0.33 * 0.0701 / 0.1875
     = 0.1234

   since C < 0.2,  set C = 0.2

   t-Vac = OD*SQRT(C*P_ext/SE) + CA
         = (120)*SQRT[(0.2)(-0.1256)/(22,500)(0.7)] + 0
         = 0.1515 in.

   t-Calc = MAX(t-Calc, t-Vac)
          = MAX(0.25,0.1515)
          = 0.25 in.

   P_max_external (Vacuum limited by bottom plate thickness)
         = -([(t - CA)/OD]^2*(S*E/C) + P_btm)
         = -([(0.25 - 0)/120]^2*(22,500*0.7/0.2) + 0.0744)
         = -0.4162 PSI or -11.53 IN. H2O
```

< FLAT BOTTOM: NON-ANNULAR SUMMARY >

Bottom Plate Material : A-240 Type 304
t.required = 0.25 in.
t.actual = 0.25 in.

```
STIFFENING RINGS (API-650)

   vs = Wind Velocity    = 0 mph
   vf = Velocity Factor = (vs/100)^2 = (0/100)^2 = 0
   Design PV = 0.2 PSI, OR 5.54 In. H2O

(REF: 'Structural Analysis and Design of Process Equipment'
      2nd Edition, Jawad)
   (Combining effects of internal vacuum with vf)

   ve = Effective Velocity Factor
      = (25.6 * vf + 144 * SF * PV) / 25.6
                     = (25.6 * 0 + 144 * 2 * 0.2) / 25.6
                     = 2.25

 <TOP COMPRESSION RING CALCULATIONS>

   Z = Required Top Comp Ring Section Modulus (per API-650 3.1.5.9.e)

     = 0 in^3, Top Comp. Ring is not required for Self-Supported Roofs
              if the requirements of either Section 3.10.5
              or 3.10.6 are met.


 <INTERMEDIATE WIND GIRDER CALCULATIONS (PER API-620 Section 5.10.6)

       ME = 28,000,000/28,000,000
          = 1

       Hu = Maximum Height of Unstiffened Shell
          = {ME*600,000*t*SQRT[t/OD]^3} / Ve)
          = {1*600,000*0.1875*SQRT[0.1875/10]^3} / 2.25
          = 128.37 ft

       Wtr    = Transposed Width of each Shell Course
              = Width*[ t_top_course / t_course ]^2.5

       Transforming Courses (1) to (2)

       Wtr(1) = 5*[ 0.1875/0.1875 ]^2.5 = 5 ft
       Wtr(2) = 5*[ 0.1875/0.1875 ]^2.5 = 5 ft
       Htr  (Height of the Transformed Shell)
            = SUM{Wtr} = 10 ft

       L0 = Unstiffened Shell Length
          = 10/1 = 10 ft


       No Intermediate Wind Girders Needed Since Hu >= L_0


    Ve_Max = {ME*600,000*t*SQRT[t/OD]^3} / L0
           = {1*600,000*0.1875*SQRT[0.1875/10]^3} / 10
           = 28.8838
```

P_ext_shell_1 (EXTERNAL PRESSURE CHECK per Jawad,
based on Ve_Max, L0, and t_top_course)
= 25.6 * (vf - Ve_Max) / (144 * SF))
= 25.6 * (0 - 28.8838) / (144 * 2))
= -2.5674 PSI or -71.15 IN. H2O

t_shell_min_1 (Shell Minimum t per Jawad,
based on L0, and Ve),
= {(L0*Ve*SQRT[OD]^3) / (ME*600,000)} ^ 0.4 (CA Incl. Later)
= {(10*2.25*SQRT[10]^3) / (1*600,000)} ^ 0.4
= 0.0675 in.

NOTE: Per User Design,
Wind Girder Calculations per Jawad N.A.

Design Length (L0) = 10 ft or 120 in.
Design Diameter (D0) = 10 ft or 120 in.

M = max(M_seismic, M_wind) = 17,039 ft-lbf

tq = thickness required for M
= M/(R^2*PI*S*E)
= 0.0008 in.

tnp (Top Course thickness available to resist external pressure)
= t_top_course - tq
= 0.1875 - 0.0008

= 0.1867 in.

Since D0/t <= 1000, Will also Perform ASME Vacuum Calculations.

CHECK FOR EXTERNAL PRESSURE: (per ASME Section VIII, UG-28)

L0/D0 = 1
D0/(t_top_course - ca_top_course) = 640
B = 1,157 <from FIG HA-1 >
A = 0.0000824 <from FIG UGO 28.0> (ref. only)

t_shell_min_2 = 3PD/(4B) + tq (CA Included later)
= (3*0.2*120.00)/(4*1,157) + 0.0008
= 0.0164 in.

P_ext_shell_2 (Per ASME VIII)
= -4*tnp*B/(3*D0)
= -4*-2.4001*1,157/(3*120.00)
= -2.4001 PSI or -66.52 IN. H2O
(Due to Top Shell Course)

t_shell_min_3 (Back Calculate Using Course Actual values),
= D0 / [(0.866*E)/(PV*(L0/D0))]^(2/5) + ca_top_course
= 120/[(0.866*28,000,000)/(0.2*(1))]^(2/5)
= 0.0701 in. (CA Incl. Later)

```
    P_ext_shell = P_ext_shell_2
       = -2.4001 PSI

       = -2.4001 PSI or -66.52 IN. H2O

    Since PV >= P_ext_shell,  No Stiffeners Required.
```

<INTERMEDIATE GIRDER CALCULATION SHELL THICKNESS SUMMARY>

NOTE: Course t.exernal values below exclude Corrosion Allowance.

```
    t.external.1 = MAX(t_shell_min _1 to _3)
                 = MAX(0.0164,0.0675,0.0701)
                 = 0.0701 in.

    t.external.2 = MAX(t_shell_min _1 to _3)
                 = MAX(0.0164,0.0675,0.0701)
                 = 0.0701 in.
```

<BOTTOM COMPRESSION RING CALCULATIONS>

Bottom Compression Ring: N.A.

```
WIND MOMENT (Using API-650 SECTION 3.11)

     vs = Wind Velocity = 0 mph
     vf = Velocity Factor = (vs/100)^2 = (0/100)^2 = 0

     hR = Height of Roof
        = R - SQRT[R^2 - (OD/2)^2]
        = 10 - SQRT[10^2 - (10/2)^2]
        = 1.331 ft

     t_ins = Thickness of Roof Insulation
           = 0 ft
     Ap_Vert = Vertical Projected Area of Roof
             = PI*([R + t_ins]^2)(Alpha/360) - OD*([R + t_ins] - hR)/2
             = PI*(10^2)(59.9499/360) - 10*(10 - 1.331)/2
             = 8.9712 ft^2

     Horizontal Projected Area of Roof (Per API-650 3.2.1.f)

     Xw = Moment Arm of UPLIFT wind force on roof
        = 0.5*OD
        = 0.5*10
        = 5 ft
     Ap = Projected Area of roof for wind moment
        = PI*R^2
        = PI*5^2
        = 78.54 ft^2
     Mw = Wind Moment = 0 ft-lbf

     W  = Net weight (PER API-650 3.11.3)
        (Force due to corroded weight of shell and
         shell-supported roof plates less
         40% of F.1.2 Uplift force.)

        = W_shell + W_roof - 0.4*P*(PI/4)(144)(OD^2)
        = 2,520 + 656 - 3*(PI/4)(144)(10^2)
        = -10,396 lbf

   NOTE: There is net uplift on the tank.

RESISTANCE TO OVERTURNING (per API-650 3.11.2)

   An unanchored Tank must meet these two criteria:
    1) 0.6*Mw + MPi < MDL/1.5
    2) Mw + 0.4MPi < (MDL + MF)/2

   Mw = Destabilizing Wind Moment = 0 ft-lbf

   MPi = Destabilizing Moment about the Shell-to-Bottom Joint from Design «
                                                                  Pressure.

       = P*(PI*OD^2/4)*(144)*(OD/2)
       = 3*(3.1416*10^2/4)*(144)*(5)
       = 169,646 ft-lbf

   MDL = Stabilizing Moment about the Shell-to-Bottom Joint from the Shell and «
                                           Roof weight supported by the Shell.
       = (W_shell + W_roof)*OD/2
       = (2,520 + 656)*5
       = 15,880 ft-lbf
```

```
ta = Bottom Plate thickness = 0.25 in.

wa = Circumferential loading of contents along Shell-To-Bottom Joint.
   = 4.67*ta*SQRT(Sy_btm*H_liq)
   = 4.67*0.25*SQRT(30,000*10)
   = 639.4661 lbf/ft

MF = Stabilizing Moment due to Bottom Plate and Liquid Weight.
   = (OD/2)*wa*PI*OD
   = (5)(639.4661)(3.1416)(10)
   = 30,134 ft-lbf

Criteria 1
0.6*(0) + 169,646 < 15,880/1.5
Since 169,646 >= 10,587, Tank must be anchored.

Criteria 2
0 + 0.4 * 169,646 < (15,880 + 30,134)/2
Since 67,858 >= 23,007, Tank must be anchored.
```

RESISTANCE TO SLIDING (per API-650 3.11.4)

```
F_wind = vF*(15 * Ap_Vert + 18 * As)
       = 0*(15 * 8.9712 + 18 * 100)
       = 0 lbf

F_friction = Maximum of 40% of Weight of Tank
     = 0.4 * (W_Roof_Corroded + W_Shell_Corroded +
              W_Btm_Corroded + W_min_Liquid)
     = 0.4 * (656 + 2,520 + 869 + 0)
           = 1,618 lbf

No anchorage needed to resist sliding since

   F_friction > F_wind
(Due to Uplift)
```

ANCHORED TANKS (per API-650 3.11.3)

```
btwind = Anchor Tension Required to Resist Wind Moment
       = 4*Mw/(D*N) - W/N
       = 4*0/(10.3333*8) - (-10,396)/8
       = 1,300 lbf
```

SEISMIC MOMENT (API-650 APPENDIX E & API-620 APPENDIX L)

```
    Ms   (Seismic Moment)
    Ms = Z*I*(C1*Ws*Xs + C1*Wr*Ht + C1*W1*X1 + C2*W2*X2)

    Z  = 0.075      Zone coefficient for zone 1 (from Table E-2)
    I  = 1          Importance Factor
    S  = 1.5        Site amplification factor (from Table E-3)

    C1 = 0.6 = Lateral earthquake force coefficient

    k  = 0.59  (factor for D/H = 1 from figure E-4)

    T  = Natural Period of First Sloshing Mode
       = k*SQRT(OD) = 0.59*SQRT(10) = 1.866

    C2 = Lateral Earthquake Force Coefficient
       = 0.75(S)/T = .75(1.5)/(1.866) = 0.6029

    From Figures E-2 & E-3
    X1_H = X1/H chart factor
    X2_H = X2/H chart factor
    W1_Wt = W1/Wt chart factor
    W2_Wt = W2/Wt chart factor
    Wt = Weight of tank contents @ Max. Liquid Level

    X1 = (X1_H)*H = (0.4044)*10 = 4.0444
    X2 = (X2_H)*H = (0.724)*10 = 7.2405
    W1 = (W1_Wt)*Wt = (0.8132)*67,665 = 55,024
    W2 = (W2_Wt)*Wt = (0.245)*67,665 = 16,578
    Ws = W_shell + W_Insulation (New Condition)
       = 2,520 + 0 = 2,520
    Wr = W_roof + Snow Load + W_Insulation (New Condition)
       = 656 + 1,634 + 0 = 2,290

    C1*Ws*Xs = 0.6*(2,520)(5) = 7,560
    C1*Wr*Ht = 0.6*(2,290)(10) = 13,740
    C1*W1*X1 = 0.6*(55,024)(4.0444) = 133,523
    C2*W2*X2 = (0.6029)(16,578)(7.2405) = 72,369

    Ms = Z*I*(C1*Ws*Xs + C1*Wr*Ht + C1*W1*X1 + C2*W2*X2)
       = (0.075)(1)(7,560 + 13,740 + 133,523 + 72,369)
       = 17,039 ft-lbf

    W_shell = Weight of Shell (New Condition)
    W_roof2 = Weight of Roof Plates Supported By Shell (New)

    wt = (W_shell + W_roof2)/(PI*OD)     (New Condition)
       = (2,520 + 656)/(PI*10)
       = 101. lbf/ft

  RESISTANCE TO OVERTURNING  (per Section E.4.1, E.4.2,
                              assuming no anchors)

    wl = 7.9*(tb1)*SQRT(Sy*G*H)
       = 7.9*(0.25)*SQRT(36,000*1.39*10)
       = 1,397 lbf/ft

       where tb1 = t - CA = 0.25 in. (for Bottom Plate)
```

```
  1.25*G*H*OD = 1.25(1.39)(10)(10)
              = 174 lbf/ft

  since wl > 1.25*G*H*OD, wl = 1.25G*H*OD
    wl = 174 lbf/ft

UNANCHORED TANKS (Section E.5.1)

  Ms/[OD^2(wt+wl)] = 17,039/[(10^2)(101. + 174)] = 0.6194

  b  = wt + 1.273(Ms)/OD^2 = max longitudinal compressive force
     = 101. + 1.273(17,039)/(10)^2 = 318 lbf/ft

  MAXIMUM ALLOWABLE SHELL COMPRESSION (Section E.5.3)

    b/(12t) = Max Longitudinal Compressive Stress
            = 318/(12*(0.1875 - 0)) = 141 PSI

    G*H*OD^2/t^2 = (1.39)(10)(10^2)/(0.1875 - 0)^2 = 39,538

    Fa = 10^6*t/(2.5*OD) + 600*SQRT(G*H)
       = (10^6)(0.1875 - 0)/(2.5*10) + (600)SQRT[(1.39)(10)]
       = 9,737 PSI

    t  = 0.1875 - 0 = 0.1875 in.    (OK since b/(12t) <= Fa)

ANCHORED TANKS (Section E.5.2)

  b  = wt + 1.273(Ms)/OD^2 = Max Longitudinal Compressive Force
     = 101. + 1.273(17,039)/(10)^2 = 318 lbf/ft

  MAXIMUM ALLOWABLE SHELL COMPRESSION (Section E.5.3)

    b/(12t) = Max Longitudinal Compressive Stress
            = 318/(12*(0.1875 - 0)) = 141 PSI

    G*H*OD^2/t^2 = (1.39)(10)(10^2)/(0.1875 - 0)^2 = 39,538

    Fa = 10^6*t/(2.5*OD) + 600*SQRT(G*H)
       = (10^6)(0.1875 - 0)/(2.5*10) + (600)SQRT[(1.39)(10)]
       = 9,737 PSI

    t  = 0.1875 - 0 = 0.1875 in.    (OK since b/(12t) <= Fa)

ANCHORAGE OF TANKS (Section E.6.1)

  N = 8           Number of Anchors
  D = 10.3333 ft    Diameter of Anchor Circle

  Net_Uplift = Net uplift due to internal pressure

  MAR = minimum anchorage resistance due to seismic moment
      = 1.273(Ms)/OD^2 + Net_Uplift/Circumference
      = 1.273(17,039)/10^2 + 30,753/(PI*10)
      = 1,196 lbf/ft circumference

  btseis = anchor tension req'd to resist seismic moment
         = MAR*D*PI/(N)
         = (1,196)(10.3333)(PI)/(8) = 4,853 lbf
```

<ANCHORAGE REQUIREMENTS>

Minimum # Anchor Bolts = 4
   NOTE: API-620 has no minimum spacing requirement, but
      per API-650 3.12.3, maximum spacing is 10' if anchorage required.

Actual # Anchor Bolts = 8
Anchorage Meets Spacing Requirements.

ANCHOR BOLT DESIGN

Bolt Material : A-193 Gr B7
Sy = 105,000 PSI

< Uplift Load Cases, per API-650 Table 3-21b >

D (tank OD) = 10 ft
P (design pressure) = 83.14 INCHES H2O
Pt (test pressure) = 1.25 * P = 103.93 INCHES H2O
Pf (failure pressure per F.6) = N.A. (see Uplift Case 3 below)
t_h (roof plate thickness) = 0.1875 in.
Mw (Wind Moment) = 0 ft-lbf
Ms (Seismic Moment) = 17,039 ft-lbf
W1 (Dead Load of Shell minus C.A. and Any
Dead Load minus C.A. other than Roof
Plate Acting on Shell)

W2 (Dead Load of Shell minus C.A. and Any
Dead Load minus C.A. including Roof
Plate minus C.A. Acting on Shell)

W3 (Dead Load of New Shell and Any
Dead Load other than Roof
Plate Acting on Shell)

For Tank with Self Supported Roof,
W1 = Corroded Shell + Shell Insulation
= 2,520 + 0
= 2,520 lbf
W2 = Corroded Shell + Shell Insulation + Corroded
Roof Plates + Roof Dead Load
= 2,520 + 0
+ 656 + 11,762 * 8.0325/144
= 3,832 lbf
W3 = New Shell + Shell Insulation
= 2,520 + 0
= 2,520 lbf

Uplift Case 1: Design Pressure Only
U = [(P - 8*t_h) * D^2 * 4.08] - W1
U = [(83.14 - 8*0.1875) * 10^2 * 4.08] - 2,520
= 30,789 lbf
bt = U / N = 3,849 lbf

Sd = 15,000 PSI
A_s_r = Bolt Root Area Req'd
A_s_r = bt/Sd
= 3,849/15,000 = 0.257 in^2

Uplift Case 2: Test Pressure Only
U = [(Pt - 8*t_h) * D^2 * 4.08] - W1
U = [(103.93 - 8*0.1875) * 10^2 * 4.08] - 2,520
= 39,271 lbf
bt = U / N = 4,909 lbf

```
     Sd = 20,000 PSI
     A_s_r = Bolt Root Area Req'd
     A_s_r = bt/Sd
           = 4,909/20,000 = 0.245 in^2

  Uplift Case 3: Failure Pressure Only
    Not applicable since if there is a knuckle on tank roof,
    or tank roof is not frangible.
    Pf (failure pressure per F.6) = N.A.

  Uplift Case 4: Wind Load Only
     U = [4 * Mw / D] - W2
     U = [4 * 0 / 10] - 3,832
       = -3,832 lbf
     bt = U / N = -479 lbf

     Sd = 0.8 * 105,000 = 84,000 PSI
     A_s_r = Bolt Root Area Req'd
     A_s_r = N.A., since Load per Bolt is zero.

  Uplift Case 5: Seismic Load Only
     U = [4 * Ms / D] - W2
     U = [4 * 17,039 / 10] - 3,832
       = 2,984 lbf
     bt = U / N = 373 lbf

     Sd = 0.8 * 105,000 = 84,000 PSI
     A_s_r = Bolt Root Area Req'd
     A_s_r = bt/Sd
           = 373/84,000 = 0.004 in^2

  Uplift Case 6: Design Pressure + Wind Load
     U = [(P - 8*t_h) * D^2 * 4.08] + [4 * Mw / D] - W1
     U = [(83.14-8*0.1875)*10^2 * 4.08]+[4*0 / 10] - 2,520
       = 30,789 lbf
     bt = U / N = 3,849 lbf

     Sd = 20,000 = 20,000 PSI
     A_s_r = Bolt Root Area Req'd
     A_s_r = bt/Sd
           = 3,849/20,000 = 0.192 in^2

  Uplift Case 7: Design Pressure + Seismic Load
     U = [(P - 8*t_h) * D^2 * 4.08] + [4 * Ms / D] - W1
     U = [(83.14-8*0.1875)*10^2 * 4.08]+[4*17,039/10]-2,520
       = 37,605 lbf
     bt = U / N = 4,701 lbf

     Sd = 0.8 * 105,000 = 84,000 PSI
     A_s_r = Bolt Root Area Req'd
     A_s_r = bt/Sd
           = 4,701/84,000 = 0.056 in^2
< ANCHOR BOLT SUMMARY >

  Bolt Root Area Req'd = 0.257 in^2

  Exclusive of Corrosion,
  Nominal Bolt Diameter Req'd = 0.75 in. (per ANSI B1.1)
```

Actual Bolt Diameter = 1.000 in.

Bolt Diameter Meets Requirements.

ANCHOR CHAIR DESIGN
(from AISI 'Steel Plate Engr Data' Dec. 92, Vol. 1, Part VII)

Entered Parameters

Chair Material:	A-240 Type 304
Top Plate Type:	DISCRETE
Chair Style:	VERT. TAPERED
a : Top Plate Width	= 4.000 in.
b : Top Plate Length	= 4.000 in.
k : Verical Plate Width	= 2.500 in.
c : Top Plate Thickness	= 0.750 in.
d : Bolt Nominal Diameter	= 1.000 in.
e : Bolt Eccentricity	= 2.000 in.
f : Outside of Top Plate to Hole Edge	= 0.625 in.
g : Distance Between Vertical Plates	= 2.000 in.
h : Chair Height	= 12.000 in.
j : Vertical Plate Thickness	= 0.500 in.
m : Bottom Plate Thickness	= 0.2500 in.
t : 1st Shell Course Thickness	= 0.1875 in.
r : Nominal Shell Radius to Tank Centerl	= 59.813 in.

Bolt Load due to Seismic (U Case 7): 4,701 LBF
Bolt Load due to Wind (U Case 6): 3,849 LBF
Bolt Load due to Uplift (U Case 1) : 4,909 LBF

Design Load per Bolt: P = 4.91 KIPS

d = Bolt Diameter = 1 in.
n = Threads per unit length = 8 TPI
A_s = Computed Bolt Root Area
= 0.7854 * (d - 1.3 / n)^2
= 0.7854 * (1 - 1.3 / 8)^2
= 0.551 in^2

Bolt Yield Load = A*Sy/1000 (KIPS)
= 0.551*105,000/1000
= 57.855 KIPS

Sts = 22,500 PSI (Allowable Tensile Stress per API-620 Table 5-1)
Per API-650 Table 3-21b, Sd = 15 KSI

Since t <= 3/8 in. and Seismic Zone is a Factor,
h_min is 12 in.

For Discrete Top Plate,
Max. Chair Height Recommended : h <= 3 * a
h_max = 3 * 4 = 12 in.

e_min = 0.886 * d + 0.572 = 1.458 in.

g_min = d + 1 = 2 in.

f_min = d/2 + 0.125 = 0.625 in.

```
c_min = SQRT[P / Sd / f * (0.375 * g - 0.22 * d)]
      = 0.527 in.

j_min = MAX(0.5, [0.04 * (h - c)])
      = MAX(0.5, [0.04 * (12.000 - 0.750)])
      = 0.5 in.

Checking Requirement: (j*k) Must Be >= (P/25)

b_min = e_min + d + 1/4
      = 1.458 + 1 + 1/4
      = 2.708 in.

<Stress due to Top Plate Thickness>
    Sd_TopPlate = P / f / c^2 * (0.375 * g - 0.22  * d)
                = 4.91/0.625/0.75^2 * (0.375 * 2 - 0.22 * 1)
                = 7.4 KSI

Chair Material Yield Stress = 30000 PSI

<Stress due to Chair Height> (For Discrete Top Plate)
    Sd_ChairHeight = P * e / t^2 * F3
      where F3 = F1 + F2,

        now F1 = (1.32 * z) / (F6 + F7)
      where F6 = (1.43 * a * h^2) / (r * t)
        and F7 = (4 * a * h^2)^(1/3)
         and z = 1 / (F4 * F5 + 1)
      where F4 = (0.177 * a * m) / SQRT(r * t)
        and F5 = (m / t)^2

     yields F5 = (0.25 / 0.1875)^2
               = 1.7778
     yields F4 = (0.177 * 4. * 0.25) / SQRT(59.8125 * 0.1875)
               = 0.0529
      yields z = 1 / (0.0529 * 1.7778 + 1)
               = 0.9141
     yields F7 = (4 * 4. * 12.^2)^(1/3)
               = 13.2077
     yields F6 = (1.43 * 4. * 12.^2) / (59.8125 * 0.1875)
               = 0.0139
     yields F1 = (1.32 * z) / (0.0139 + 13.2077)
               = 0.0139

        now F2 = 0.031 / SQRT(r * t)
     yields F2 = 0.031 / SQRT(59.8125 * 0.1875)
               = 0.0093
     yields F3 = 0.0139 + 0.0093)
               = 0.0232
yields  Sd_ChairHeight = 4.909 * 2. / 0.1875^2 * 0.0232
                 = 6.4739 KSI

Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

For Shell Course material: A-240 Type 304,
  using Design Stress = 22.5 ksi
```

< ANCHOR CHAIR SUMMARY >

Sd_TopPlate Meets Design Calculations
(within 105% of Sd)
Sd_ChairHeight Meets Design Calculations
(within 105% of Sd)

M I FAB - Y08-125
TANK REPORT: Printed - 11/19/2008 11:41:28 AM

TABLE 1A: NOZZLES & MANWAYS

NAME	TYPE	SIZE (in)	FLANGE FACING	SCH.	ELEV. ON SHELL (ft)	ORIEN (Deg.	REPAD t (in)	REPAD Do or L (in)	REPAD W (in)	REPAD CA (in)
A & L	RFNZ	6	RFSO	STD	N.A.	0	-	-	-	-
C	RFMW	30	RFSO	STD	N.A.	0	-	-	-	-
H	SHNZ	30	RFSO	STD	2	0	-	-	-	-

TABLE 1B: NOZZLES & MANWAYS

NAME	MATERIAL	E1	Ex	t_n (in)	ca_n (in)	L_ip (in)	L_ep (in)	tw1 (in)	tw2 (in)
A & L	N.A.	--	--	--	--	--	--	--	--
C	A-240 Type 304	0.7	1	0.187	0	0	6	0.187	0
H	A-312 UNS S3125	0.7	1	0.187	0	0	6	0.187	0

Roof Sts = 22,500 PSI (Allowable Tensile Stress per API-620 Table 5-1)

< Nozzle A & L Reinforcement Requirements >
(Per API-650 Section 3.8.5.1 and other references below)

NOZZLE Description : 6in. STD RFSO

MOUNTED ON ROOF; Elevation = 0 ft.
ROOF PARAMETERS:
(Per User Setting, t-Basis = API 650 default 1/4 in.)
t_c = 0.1875 in.
t_Basis = 0.25 in.

(FOR ROOF NOZZLE,
REF. API-650 FIG 3-16, TABLE 3-14 AND FOOTNOTE A OF TABLE 3-14,
or API-650 FIG 3-17, TABLE 3-15 AND FOOTNOTE A OF TABLE 3-15)

Since Roof Nozzle size <= 6 NPS,
t_rpr = 0 in.

No Repad Required per FOOTNOTE A, Table 3-14

```
< Manway C Reinforcement Requirements (per API-620 Section 5.16) >

   Manway Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

   Roof Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

   < EXTERNAL PRESSURE (Design Mode) = 0.2 PSI >
   Material : A-240 Type 304
   ID_n (Manway ID) : 29.25 in.
   ca_n (Corrosion Allowance for Manway Neck) : 0 in.
   ID2_n (Corroded Manway ID) = ID_n + 2 * ca_n : 29.25 in.
   t_n (Nominal Manway Neck thickness) : 0.1875 in.
   E (Tank Joint Efficiency) : 0.7
   E1 (Manway Neck Joint Efficiency) : 0.7
   Ex (Area Joint Efficiency on which Manway is Mounted) : 1
   tw1 (Fillet Weld at Manway Neck OD) : 0.1875 in.
   t_rp (Manway Repad Nominal Thickness) : 0 in.
   ca_rp (Manway Repad Corrosion Allow.) : 0 in.
   D_rp (Manway Repad Do or L) : 0 in.
   tw2 = tw2c = 0 in.
   L_ip (Internal Projected Length of Manway Neck) : 0 in.
   L_ep (External Projected Length of Manway Neck) : 6 in.
   H_n (Nominal Manway Elevation on Shell) : 0 ft.

   P_n (Max. Internal Pressure on Manway, Including Static Liquid Head),
       = P = 3 PSI

FOR COMPONENT ON WHICH MANWAY IS MOUNTED:
   t_c (Actual Thickness) : 0.1875 in.
   t_cr (Required Thickness, Inclusive of Corrosion) : 0.062 in.
   ca_c (Corrosion Allowance) : 0 in.
   S_cd (Allowable Design Stress) : 22,500 PSI

   f_n (Manway Stress Reduction Factor),
       = MIN[(Sts/S_cd), 1]
       = MIN[(22,500 / 22,500), 1]
       = 1

   L_ip2 = MIN[L_ip, 2.5*(t_c - ca_c), 2.5*(t_n - ca_n - ca_c)]
         = MIN[0, 2.5*(0.1875 - 0), 2.5*(0.1875 - 0 - 0)]
         = 0 in.

   t_nr (Required Manway Thickness, per ASME Section VIII, UG-28)

     L0/D0 = L_ep/(ID_n + 2*t_n) = 0.2025
     D0/(t_n - ca_n) = 158
     B = 12,817    <from FIG HA-1 >
     A = 0.004    <from FIG UGO-28.0> (ref. only)

   t_nr = 3PD/(4B) + CA
        = (3*0.2*29.63)/(4*12,817) + 0
   ---> = 0.0003 in.
```

```
Manway Areas Providing Reinforcement:
   A1_c (Available Component wall on which Manway is mounted),
        = ID_n * (t_c - t_cr) - 2*t_n*(t_c - t_cr)*(1-f_n)
        = 29.25 * (0.1875 - 0.062) - 2 * 0.1875 * (0.1875 - 0.062)*(1-1)
        = 3.6709 in^2.
   A2_n (Available Manway neck thickness),
        = 5 * MAX[(t_n - t_nr),0] * MIN[(t_n - ca_n),(t_c - ca_c)] * f_n
        = 5 * MAX[(0.1875-0.0003),0]*MIN[(0.1875-0),(0.1875-0)] * 1
        = 0.1755 in^2.
   A3_n (Available Internal Projection of Manway neck),
        = 2 * (t_n - ca_n - ca_c) * L_ip2 * f_n
        = 2 * (0.1875 - 0 - 0) * 0 * 1
        = 0 in^2.
   A4_n (Available Inner and Outer fillet welds),
        = tw1 ^2 + tw2c ^2
        = (0.1875)^2 + (0) ^2
        = 0.0352 in^2.
   A5_n = 0 in^2 (No Reinforcement Area due to Repad)

   A_a (Actual Reinforcement Area)
        = A_1c + A2_n + A3_n + A4_n + A5_n
        = 3.6709 + 0.1755 + 0 + 0.0352 + 0
        = 3.882 in^2.

Actual Reinforcement Area for Manway C : A_a = 3.882 in^2.

   A_r (Required Reinforcement Area)
       = 0.5 * (t_cr - ca_c) * [(ID_n + 2 * ca_n) + 2 * (t_n - ca_n)*(1-f_n)]
       = 0.5*(0.062-0)*[(29.25 + 2*0) + 2*(0.1875-0)*(1-1)]
       = 0.907 in^2.

Under External Pressure:
 Required Reinforcement Area for Manway C : A_r = 0.907 in^2.

   Since A1_c + A2_n + A3_n + A4_n >= A_r,

   A5_n_Calc = 0 in^2  (Repad Reinforcement Area Not Required)

   L_nn (Length of Manway Neck Contributing to Reinforcement: REFERENCE ONLY),
        = 2.5 * MIN[(t_n - ca_n),(t_c - ca_c)] + (t_rp - ca_rp)
        = 2.5 * MIN[(0.1875 - 0),(0.1875 - 0)] + (0)
        = 0.4688 in.
```

```
   < INTERNAL PRESSURE (Design Mode) = 3 PSI >
   Material : A-240 Type 304
   ID_n (Manway ID) : 29.25 in.
   ca_n (Corrosion Allowance for Manway Neck) : 0 in.
   ID2_n (Corroded Manway ID) = ID_n + 2 * ca_n : 29.25 in.
   t_n (Nominal Manway Neck thickness) : 0.1875 in.
   E (Tank Joint Efficiency) : 0.7
   E1 (Manway Neck Joint Efficiency) : 0.7
   Ex (Area Joint Efficiency on which Manway is Mounted) : 1
   tw1 (Fillet Weld at Manway Neck OD) : 0.1875 in.
   t_rp (Manway Repad Nominal Thickness) : 0 in.
   ca_rp (Manway Repad Corrosion Allow.) : 0 in.
   D_rp (Manway Repad Do or L) : 0 in.
   tw2 = tw2c = 0 in.
   L_ip (Internal Projected Length of Manway Neck) : 0 in.
   L_ep (External Projected Length of Manway Neck) : 6 in.
   H_n (Nominal Manway Elevation on Shell) : 0 ft.

   P_n (Max. Internal Pressure on Manway, Including Static Liquid Head),
       = P = 3 PSI

FOR COMPONENT ON WHICH MANWAY IS MOUNTED:
   t_c (Actual Thickness) : 0.1875 in.
   t_cr (Required Thickness, Inclusive of Corrosion) : 0.0202 in.
   ca_c (Corrosion Allowance) : 0 in.
   S_cd (Allowable Design Stress) : 22,500 PSI

   f_n (Manway Stress Reduction Factor),
       = MIN[(Sts/S_cd), 1]
       = MIN[(22,500 / 22,500), 1]
       = 1

   L_ip2 = MIN[L_ip, 2.5*(t_c - ca_c), 2.5*(t_n - ca_n - ca_c)]
         = MIN[0, 2.5*(0.1875 - 0), 2.5*(0.1875 - 0 - 0)]
         = 0 in.

   t_nr (Required Manway Thickness)
        = [P_n * (0.5 * ID_n + CA_n)]/(Sa * E1) + CA_n
        = [3 * (0.5 * 29.25 + 0)]/(22,500 * 0.7) + 0
   ---> = 0.0028 in.
```

```
Manway Areas Providing Reinforcement:
   A1_c (Available Component wall on which Manway is mounted),
        = ID_n * (t_c - t_cr) - 2*t_n*(t_c - t_cr)*(1-f_n)
        = 29.25 * (0.1875 - 0.0202) - 2 * 0.1875 * (0.1875 - 0.0202)*(1-1)
        = 4.8935 in^2.
   A2_n (Available Manway neck thickness),
        = 5 * MAX[(t_n - t_nr),0] * MIN[(t_n - ca_n),(t_c - ca_c)] * f_n
        = 5 * MAX[(0.1875-0.0028),0]*MIN[(0.1875-0),(0.1875-0)] * 1
        = 0.1732 in^2.
   A3_n (Available Internal Projection of Manway neck),
        = 2 * (t_n - ca_n - ca_c) * L_ip2 * f_n
        = 2 * (0.1875 - 0 - 0) * 0 * 1
        = 0 in^2.
   A4_n (Available Inner and Outer fillet welds),
        = tw1 ^2 + tw2c ^2
        = (0.1875)^2 + (0) ^2
        = 0.0352 in^2.
   A5_n = 0 in^2 (No Reinforcement Area due to Repad)

   A_a (Actual Reinforcement Area)
        = A_1c + A2_n + A3_n + A4_n + A5_n
        = 4.8935 + 0.1732 + 0 + 0.0352 + 0
        = 5.102 in^2.

Actual Reinforcement Area for Manway C : A_a = 5.102 in^2.

   A_r (Required Reinforcement Area)
       = (t_cr - ca_c) * E / Ex * [(ID_n + 2 * ca_n) + 2*(t_n - ca_n)*(1-f_n)]
       = (0.0202 - 0) * 0.7 / 1 * [(29.25 + 2*0)
          + 2 * (0.1875 - 0) * (1 - 1)]
       = 0.414 in^2.

Under Internal Pressure:
 Required Reinforcement Area for Manway C : A_r = 0.414 in^2.

   Since A1_c + A2_n + A3_n + A4_n >= A_r,

   A5_n_Calc = 0 in^2  (Repad Reinforcement Area Not Required)

   L_nn (Length of Manway Neck Contributing to Reinforcement: REFERENCE ONLY),
        = 2.5 * MIN[(t_n - ca_n),(t_c - ca_c)] + (t_rp - ca_rp)
        = 2.5 * MIN[(0.1875 - 0),(0.1875 - 0)] + (0)
        = 0.4688 in.
```

```
< Nozzle H Reinforcement Requirements (per API-620 Section 5.16) >

   Nozzle Sts = 28,200 PSI   (Allow. Tensile Stress   no API-620 Reference)
   NOTE : The API-620 Table 5-1 Value was not found.

   Shell Sts = 22,500 PSI  (Allowable Tensile Stress per API-620 Table 5-1)

   < EXTERNAL PRESSURE (Design Mode) = 0.2 PSI >
   Material : A-312 UNS S31254 WLD PIPE
   ID_n (Nozzle ID) : 29.25 in.
   ca_n (Corrosion Allowance for Nozzle Neck) : 0 in.
   ID2_n (Corroded Nozzle ID) = ID_n + 2 * ca_n : 29.25 in.
   t_n (Nominal Nozzle Neck thickness) : 0.1875 in.
   E (Tank Joint Efficiency) : 0.7
   E1 (Nozzle Neck Joint Efficiency) : 0.7
   Ex (Area Joint Efficiency on which Nozzle is Mounted) : 1
   tw1 (Fillet Weld at Nozzle Neck OD) : 0.1875 in.
   t_rp (Nozzle Repad Nominal Thickness) : 0 in.
   ca_rp (Nozzle Repad Corrosion Allow.) : 0 in.
   D_rp (Nozzle Repad Do or L) : 0 in.
   tw2 = tw2c = 0 in.
   L_ip (Internal Projected Length of Nozzle Neck) : 0 in.
   L_ep (External Projected Length of Nozzle Neck) : 6 in.
   H_n (Nominal Nozzle Elevation on Shell) : 2 ft.

   P_n (Max. Internal Pressure on Nozzle, Including Static Liquid Head),
       = P + G * 0.433 * (Liq. Level - H_n + 0.5 * ID_n + CA_n)
       = 3 + 1.39 * 0.433 * (10 - 2 + 0.5 * 2.4375 + 0)
       = 8.5485 PSI

FOR COMPONENT ON WHICH NOZZLE IS MOUNTED:
   t_c (Actual Thickness) : 0.1875 in.
   t_cr (Required Thickness, Inclusive of Corrosion) : 0.033 in.
   ca_c (Corrosion Allowance) : 0 in.
   S_cd (Allowable Design Stress) : 22,500 PSI

   f_n (Nozzle Stress Reduction Factor),
       = MIN[(Sts/S_cd), 1]
       = MIN[(28,200 / 22,500), 1]
       = 1

   L_ip2 = MIN[L_ip, 2.5*(t_c - ca_c), 2.5*(t_n - ca_n - ca_c)]
         = MIN[0, 2.5*(0.1875 - 0), 2.5*(0.1875 - 0 - 0)]
         = 0 in.

   t_nr (Required Nozzle Thickness, per ASME Section VIII, UG-28)

     L0/D0 = L_ep/(ID_n + 2*t_n) = 0.2025
     D0/(t_n - ca_n) = 158
     B = 12,941    <from FIG HA-2 >
     A = 0.004   <from FIG UGO-28.0> (ref. only)

   t_nr = 3PD/(4B) + CA
        = (3*0.2*29.63)/(4*12,941) + 0
   ---> = 0.0003 in.
```

```
Nozzle Areas Providing Reinforcement:
   A1_c (Available Component wall on which Nozzle is mounted),
        = ID_n * (t_c - t_cr) - 2*t_n*(t_c - t_cr)*(1-f_n)
        = 29.25 * (0.1875 - 0.033) - 2 * 0.1875 * (0.1875 - 0.033)*(1-1)
        = 4.5191 in^2.
   A2_n (Available Nozzle neck thickness),
        = 5 * MAX[(t_n - t_nr),0] * MIN[(t_n - ca_n),(t_c - ca_c)] * f_n
        = 5 * MAX[(0.1875-0.0003),0]*MIN[(0.1875-0),(0.1875-0)] * 1
        = 0.1755 in^2.
   A3_n (Available Internal Projection of Nozzle neck),
        = 2 * (t_n - ca_n - ca_c) * L_ip2 * f_n
        = 2 * (0.1875 - 0 - 0) * 0 * 1
        = 0 in^2.
   A4_n (Available Inner and Outer fillet welds),
        = tw1 ^2 + tw2c ^2
        = (0.1875)^2 + (0) ^2
        = 0.0352 in^2.
   A5_n = 0 in^2 (No Reinforcement Area due to Repad)

   A_a (Actual Reinforcement Area)
        = A_1c + A2_n + A3_n + A4_n + A5_n
        = 4.5191 + 0.1755 + 0 + 0.0352 + 0
        = 4.73 in^2.

Actual Reinforcement Area for Nozzle H : A_a = 4.73 in^2.

   A_r (Required Reinforcement Area)
       = 0.5 * (t_cr - ca_c) * [(ID_n + 2 * ca_n) + 2 * (t_n - ca_n)*(1-f_n)]
       = 0.5*(0.033-0)*[(29.25 + 2*0) + 2*(0.1875-0)*(1-1)]
       = 0.483 in^2.

Under External Pressure:
 Required Reinforcement Area for Nozzle H : A_r = 0.483 in^2.

   Since A1_c + A2_n + A3_n + A4_n >= A_r,

   A5_n_Calc = 0 in^2  (Repad Reinforcement Area Not Required)

   L_nn (Length of Nozzle Neck Contributing to Reinforcement: REFERENCE ONLY),
        = 2.5 * MIN[(t_n - ca_n),(t_c - ca_c)] + (t_rp - ca_rp)
        = 2.5 * MIN[(0.1875 - 0),(0.1875 - 0)] + (0)
        = 0.4688 in.
```

```
< INTERNAL PRESSURE (Design Mode) = 3 PSI >
Material : A-312 UNS S31254 WLD PIPE
ID_n (Nozzle ID) : 29.25 in.
ca_n (Corrosion Allowance for Nozzle Neck) : 0 in.
ID2_n (Corroded Nozzle ID) = ID_n + 2 * ca_n : 29.25 in.
t_n (Nominal Nozzle Neck thickness) : 0.1875 in.
E (Tank Joint Efficiency) : 0.7
E1 (Nozzle Neck Joint Efficiency) : 0.7
Ex (Area Joint Efficiency on which Nozzle is Mounted) : 1
tw1 (Fillet Weld at Nozzle Neck OD) : 0.1875 in.
t_rp (Nozzle Repad Nominal Thickness) : 0 in.
ca_rp (Nozzle Repad Corrosion Allow.) : 0 in.
D_rp (Nozzle Repad Do or L) : 0 in.
tw2 = tw2c = 0 in.
L_ip (Internal Projected Length of Nozzle Neck) : 0 in.
L_ep (External Projected Length of Nozzle Neck) : 6 in.
H_n (Nominal Nozzle Elevation on Shell) : 2 ft.

P_n (Max. Internal Pressure on Nozzle, Including Static Liquid Head),
    = P + G * 0.433 * (Liq. Level - H_n + 0.5 * ID_n + CA_n)
    = 3 + 1.39 * 0.433 * (10 - 2 + 0.5 * 2.4375 + 0)
    = 8.5485 PSI

FOR COMPONENT ON WHICH NOZZLE IS MOUNTED:
t_c (Actual Thickness) : 0.1875 in.
t_cr (Required Thickness, Inclusive of Corrosion) : 0.0344 in.
ca_c (Corrosion Allowance) : 0 in.
S_cd (Allowable Design Stress) : 22,500 PSI

f_n (Nozzle Stress Reduction Factor),
    = MIN[(Sts/S_cd), 1]
    = MIN[(28,200 / 22,500), 1]
    = 1

L_ip2 = MIN[L_ip, 2.5*(t_c - ca_c), 2.5*(t_n - ca_n - ca_c)]
      = MIN[0, 2.5*(0.1875 - 0), 2.5*(0.1875 - 0 - 0)]
      = 0 in.

t_nr (Required Nozzle Thickness)
     = [P_n * (0.5 * ID_n + CA_n)]/(Sa * E1) + CA_n
     = [8.5485 * (0.5 * 29.25 + 0)]/(28,200 * 0.7) + 0
---> = 0.0063 in.
```

```
Nozzle Areas Providing Reinforcement:
   A1_c (Available Component wall on which Nozzle is mounted),
        = ID_n * (t_c - t_cr) - 2*t_n*(t_c - t_cr)*(1-f_n)
        = 29.25 * (0.1875 - 0.0344) - 2 * 0.1875 * (0.1875 - 0.0344)*(1-1)
        = 4.4782 in^2.
   A2_n (Available Nozzle neck thickness),
        = 5 * MAX[(t_n - t_nr),0] * MIN[(t_n - ca_n),(t_c - ca_c)] * f_n
        = 5 * MAX[(0.1875-0.0063),0]*MIN[(0.1875-0),(0.1875-0)] * 1
        = 0.1698 in^2.
   A3_n (Available Internal Projection of Nozzle neck),
        = 2 * (t_n - ca_n - ca_c) * L_ip2 * f_n
        = 2 * (0.1875 - 0 - 0) * 0 * 1
        = 0 in^2.
   A4_n (Available Inner and Outer fillet welds),
        = tw1 ^2 + tw2c ^2
        = (0.1875)^2 + (0) ^2
        = 0.0352 in^2.
   A5_n = 0 in^2 (No Reinforcement Area due to Repad)

   A_a (Actual Reinforcement Area)
        = A_1c + A2_n + A3_n + A4_n + A5_n
        = 4.4782 + 0.1698 + 0 + 0.0352 + 0
        = 4.683 in^2.

Actual Reinforcement Area for Nozzle H : A_a = 4.683 in^2.

   A_r (Required Reinforcement Area)
       = (t_cr - ca_c) * E / Ex * [(ID_n + 2 * ca_n) + 2*(t_n - ca_n)*(1-f_n)]
       = (0.0344 - 0) * 0.7 / 1 * [(29.25 + 2*0)
         + 2 * (0.1875 - 0) * (1 - 1)]
       = 0.704 in^2.

Under Internal Pressure:
 Required Reinforcement Area for Nozzle H : A_r = 0.704 in^2.

   Since A1_c + A2_n + A3_n + A4_n >= A_r,

   A5_n_Calc = 0 in^2  (Repad Reinforcement Area Not Required)

   L_nn (Length of Nozzle Neck Contributing to Reinforcement: REFERENCE ONLY),
        = 2.5 * MIN[(t_n - ca_n),(t_c - ca_c)] + (t_rp - ca_rp)
        = 2.5 * MIN[(0.1875 - 0),(0.1875 - 0)] + (0)
        = 0.4688 in.
```

CAPACITIES and WEIGHTS

Shell capacity to upper TL : 5,838 gal

	New Condition	Corroded
Shell	2,520 lbf	2,520 lbf
Roof Plates	656 lbf	656 lbf
Bottom	869 lbf	869 lbf
Total	4,045 lbf	4,045 lbf

Weight of Tank, Empty	:	4,045 lbf
Weight of Tank, Full	:	72,347 lbf
Weight of Tank, Full of Water	:	53,183 lbf
Foundation Area Req'd	:	79 ft^2
Foundation Loading, Empty	:	51.2 lbf/ft^2
Foundation Loading, Full	:	915.78 lbf/ft^2
Foundation Loading, Full of Water	:	673.2 lbf/ft^2

MAWP & MAWV SUMMARY FOR Y08-125

MAXIMUM CALCULATED INTERNAL PRESSURE

MAWP = 15 PSI or 415.7 IN. H2O (per API-620)

MAWP = Maximum Calculated Internal Pressure (due to shell)
= 15 PSI or 415.7 IN. H2O

MAWP = Maximum Calculated Internal Pressure (due to roof)
(Roof also Per F.1.3 and F.7.5.c)
= 15 PSI or 415.7 IN. H2O

TANK MAWP = 15 PSI or 415.7 IN. H2O

MAXIMUM CALCULATED EXTERNAL PRESSURE

MAWV = Maximum Calculated External Pressure (due to shell)
= -2.4001 PSI or -66.52 IN. H2O

MAWV = Maximum Calculated External Pressure (due to roof)
= -4.549 PSI or -126.07 IN. H2O

MAWV = Maximum Calculated External Pressure (due to bottom plate)
= -0.4162 PSI or -11.53 IN. H2O

TANK MAWV = -0.4162 PSI or -11.53 IN. H2O

IV. B. VENDOR REVISED CALCULATIONS

From: Steve Williams [swilliams@imperialsteeltank.com]
Sent: Wednesday, April 27, 2011 11:31 AM
To: Richard Schmitt
Subject: RE: Liquid Argon Tank; FERMILAB P.O. 583306: Job Y08-125
Attachments: 20110427113357.pdf; 20110427113246.pdf

Richard,
Attached is a statement on the applicable letterhead confirming that the subject tank was fabricated according to the rules of API 620.

Regarding the bottom, our software automatically defaults to ¼" minimum thickness for the bottom for both API 650 and 620 designs. This minimum is for carbon steel bottoms. Both codes have an Appendix S covering stainless steel construction which allows the bottom minimum thickness to be reduced to 3/16". We ran the basic vessel parameters (without nozzles) through our current edition of the design software and attached are those pages that were impacted by the change in bottom minimum thickness. The page numbers may not correspond with the original copy due to changes in the software report format but the 3/16" bottom is adequate.

Regards,
Steven Williams
Imperial Steel Tank Company
office: 815-308-3400 x103
direct: 815-600-8607
fax: 815-308-3376

From: Richard Schmitt [mailto:rlschmitt@fnal.gov]
Sent: Tuesday, April 26, 2011 4:47 PM
To: Steve Williams
Subject: Liquid Argon Tank; FERMILAB P.O. 583306: Job Y08-125

Steve,

The documentation sent last week was a big help to our approval process. Would you also please send a statement that the tank was constructed according to the rules of API 620, as described in paragraph 8.3.2?

The calculations are very thorough, but there is a discrepancy regarding the bottom thickness. The bill of material specifies 3/16 inch but the calculations are for 0.25 inch thickness. We checked the actual thickness and found it to be 3/16 inch. The only place this has any significance change in the results is for the external pressure. Is it possible to re-run the calculations using the thinner material?

Richard Schmitt
630-840-4849
The image cannot be displayed. Your computer may not... FERMILAB

MIDWEST IMPERIAL STEEL FABRICATORS, LLC
400 S. LaGRANGE ROAD, FRANKFORT, ILLINOIS 60423

CUSTOMER
FERMI LAB
KIRK ROAD & WILSON STREET
BATAVIA, IL 60510

CUSTOMER PURCHASE ORDER
583306

DESIGN CALCULATIONS FOR

LIQUID ARGON TANK
TAG # ME-444715
120"OD x 120" SEAM / SEAM
WITH DISHED ROOF AND FLAT BOTTOM

Vessel designed with Etank 2000

M I FAB JOB No.	**Y08-125**
DESIGN CODE	API 620 10th Edition, Feb 2002
DESIGN PRESSURE	3 psi internal / 0.2 psi external
DESIGN TEMPERATURE	-320 TO 100 DEGREES F
SERIAL NUMBER	Y08-125
YEAR BUILT	2009
RADIOGRAPHY	None
POST WELD HEAT TREATMENT	None
CONSTRUCTION TYPE	Welded

Partial Revision (for 3/16" thick bottom plate)
Please refer to design calculations dated 11-19-08 for the balance of the vessel design calculations

SIGNATURES

APPROVED: Steve Williams **DATE:** 4/27/11

SUMMARY OF DESIGN DATA and REMARKS

Job	: Y08-125
Date of Calcs.	: 4/27/2011 , 10:05 AM
Mfg. or Insp. Date	: 11/19/2008
Designer	: SCW
Project	: FERMI LAB P.O. 583306
Tag Number	: ME-444715
Plant	: FERMI LAB
Plant Location	: FERMI LAB
Site	: FERMI LAB
Design Basis	: API-620 10th Edition, Feb 2002

- TANK NAMEPLATE INFORMATION

- Operating Ratio: 0.4
- Design Standard:
- API-620 10th Edition, Feb 2002 -
- API-650 Appendices Used: F.1.3, E -
- Roof : A-240 Type 304: 0.1875in. -
- Shell (2): A-240 Type 304: 0.1875in. -
- Shell (1): A-240 Type 304: 0.1875in. -
- Bottom : A-240 Type 304: 0.1875in. -

Design Internal Pressure = 3 PSI or 83.14 IN. H2O
Design External Pressure = -0.2 PSI or -5.54 IN. H2O

MAWP = 15.0000 PSI or 415.70 IN. H2O
MAWV = -0.2480 PSI or -6.87 IN. H2O

OD of Tank = 10 ft
Shell Height = 10 ft
S.G. of Contents = 1.39
Max. Liq. Level = 10 ft

Design Temperature = 100 °F
Tank Joint Efficiency = 0.7

Ground Snow Load = 20 lbf/ft^2
Roof Live Load = 20 lbf/ft^2
Design Roof Dead Load = 0 lbf/ft^2

Basic Wind Velocity = 0 mph
Wind Importance Factor = 1
Using Seismic Method: API-650 10th Ed.
  Seismic Zone = 1
  Site Amplification Factor = 1.5
  Importance Factor = 1

DESIGN NOTES

NOTE 1 : Per API-650 F.7.6 - Hydro test pressure = 1.25 * P
= 3.75 PSI or 103.93 IN. H2O

SUMMARY OF RESULTS

Shell Material Summary (Bottom is 1)

Shell #	Width (ft)	Material	Sts (psi)	Sca (psi)	Weight (lbf)	CA (in)
		Ratio = (t-CA)/R = (0.1875 - 0)/60 = 0.0031				
2	5	A-240 Type 304	22,500	3,125	1,260	0
		Ratio = (t-CA)/R = (0.1875 - 0)/60 = 0.0031				
1	5	A-240 Type 304	22,500	3,125	1,260	0
Total Weight					2,520	

Shell API 620 Summary (Bottom is 1)

Shell #	t.int620 (in.)	t.ext620 (in.)	t.required (in.)	t.actual (in.)
2	0.0229	0.0769	0.1875	0.1875
1	0.0344	0.0769	0.1875	0.1875

Self Supported Umbrella Roof;   Material = A-240 Type 304

t.required = 0.062 in.
t.actual = 0.1875 in.
Roof Joint Efficiency = 0.7

Weight = 656 lbf

Bottom Type: Flat Bottom: Non-Annular
Bottom Floor Material = A-240 Type 304
t.required = 0.1875 in.
t.actual = 0.1875 in.
Bottom Joint Efficiency = 0.7

Total Weight of Bottom = 674 lbf

ANCHOR BOLTS: (8) 1in. UNC Bolts, A-193 Gr B7

TOP END STIFFENER: NONE, , 0 lbf

```
FLAT BOTTOM: NON-ANNULAR PLATE DESIGN

   Bottom Plate Material :  A-240 Type 304
   Annular Bottom Plate Material :  A-36

<Weight of Bottom Plate>

   Bottom_Area = PI/4*(Bottom_OD)^2
               = PI/4*(124.)^2
               = 12,076 in^2

   Weight = Density * t.actual * Bottom_Area
          = 0.2975 * 0.1875 * 12,076
          = 674 lbf   (New)
          = 674 lbf   (Corroded)

< API-620 >

   t_min = 0.1875 + CA = 0.1875 + 0 = 0.1875 in. (per Section S.3.5.1)

   t-Calc = t_min = 0.1875 in.
   Calculation of Hydrostatic Test Stress & Product Design Stress
      (per API-650 Section 5.5.1)

   t_1 : Bottom (1st) Shell Course thickness.

   H'= Max. Liq. Level + P(psi)/(0.433)
     = 10 + (3)/(0.433) = 16.9284 ft

   St = Hydrostatic Test Stress in Bottom (1st) Shell Course
      = (2.6)(OD)(H' - 1)/t_1
      = (2.6)(10)(16.9284 - 1)/(0.1875)
      = 2,209 PSI.   (Within 24900 PSI limit for Non-Annular Bottom)

   Sd = Product Design Stress in Bottom (1st) Shell Course
      = (2.6)(OD)(H' - 1)(G)/(t_1 - ca_1)
      = (2.6)(10)(16.9284 - 1)(1.39)/(0.1875)
      = 3,070 PSI.   (Within 23200 PSI limit for Non-Annular Bottom)

 --------------------------


< Vacuum Calculations >  (per ASME Section VIII Div. 1)

   Weight of Corr. Bottom Plate Resisting External Vacuum

   P_btm = 0.2975 * 0.1875
         = 0.0558 PSI or 1.55 IN. H2O

   P_ext = PV + P_btm = -0.2 + 0.0558 = -0.1442 PSI or -4.00 IN. H2O
     = -0.1442 PSI

   td_ext = (t-Calc - CA)     (1st course)
          = (0.0769 - 0)
          = 0.0769 in.

   ts = (t.actual - CA)   (1st course)
      = (0.1875 - 0)
      = 0.1875 in.
```

```
C = 0.33 * td_ext / ts
  = 0.33 * 0.0769 / 0.1875
  = 0.1353

since C < 0.2,  set C = 0.2

t-Vac = OD*SQRT(C*P_ext/SE) + CA
      = (120)*SQRT[(0.2)(-0.1442)/(22,500)(0.7)] + 0
      = 0.1624 in.

t-Calc = MAX(t-Calc, t-Vac)
       = MAX(0.1875,0.1624)
       = 0.1875 in.

P_max_external (Vacuum limited by bottom plate thickness)
      = -([(t - CA)/OD]^2*(S*E/C) + P_btm)
      = -([(0.1875 - 0)/120]^2*(22,500*0.7/0.2) + 0.0558)
      = -0.248 PSI or -6.87 IN. H2O
```

< FLAT BOTTOM: NON-ANNULAR SUMMARY >

```
Bottom Plate Material :  A-240 Type 304
t.required = 0.1875 in.
t.actual = 0.1875 in.
```

```
NET UPLIFT DUE TO INTERNAL PRESSURE
   (See roof report for calculations)
   Net_Uplift = 30,753 lbf
   Anchorage REQUIRED for internal pressure.
   Bolt Spacing = 10 ft, Min # Anchor Bolts = 6

WIND MOMENT (Using API-650 SECTION 5.11)

     vs = Wind Velocity = 0 mph
     vf = Velocity Factor = (vs/100)^2 = (0/100)^2 = 0

     Wind_Uplift = Iw * 30 * vf
                 = 1 * 30 * 0
                 = 0 lbf/ft^2

     API-650 5.2.1.k Uplift Check
     P_F41 = WCtoPSI(0.962*Fy*A*TAN(Theta)/D^2 + 8*t_h)
     P_F41 = WCtoPSI(0.962*30,000*0*0.8333/10^2 + 8*0.1875)
           = 0.0541 PSI
     Limit  Wind_Uplift/144+P  to  1.6*P_F41
     Wind_Uplift/144 + P = 3 PSI
     1.6*P_F41 = 0.0866 PSI

     Wind_Uplift/144 + P = MIN(Wind_Uplift/144 + P, 1.6*P_F41)
     Wind_Uplift/144 = MIN(Wind_Uplift/144, 1.6*P_F41 - P)
     Wind_Uplift = MIN(Wind_Uplift, (1.6*P_F41 - P) * 144)
                 = MIN(0,-419.5354)
                 = -419.5354 lbf/ft^2
     Wind_Uplift set to zero since cannot be negative.

     hR = Height of Roof
        = R - SQRT[R^2 - (OD/2)^2]
        = 10 - SQRT[10^2 - (10/2)^2]
        = 1.331 ft

     t_ins = Thickness of Roof Insulation
           = 0 ft
     Ap_Vert = Vertical Projected Area of Roof
             = PI*([R + t_ins]^2)(Alpha/360) - OD*([R + t_ins] - hR)/2
             = PI*(10^2)(59.9499/360) - 10*(10 - 1.331)/2
             = 8.9712 ft^2


     Horizontal Projected Area of Roof (Per API-650 5.2.1.f)

     Xw = Moment Arm of UPLIFT wind force on roof
        = 0.5*OD
        = 0.5*10
        = 5 ft
     Ap = Projected Area of roof for wind moment
        = PI*R^2
        = PI*5^2
        = 78.54 ft^2
     Mw = Wind Moment = 0 ft-lbf

     W  = Net weight (PER API-650 5.11.3)
        (Force due to corroded weight of shell and
         shell-supported roof plates less
         40% of F.1.2 Uplift force.)
```

```
        = W_shell + W_roof - 0.4*P*(PI/4)(144)(OD^2)
        = 2,520 + 656 - 3*(PI/4)(144)(10^2)
        = -10,396 lbf

   NOTE: There is net uplift on the tank.

RESISTANCE TO OVERTURNING (per API-650 5.11.2)

   An unanchored Tank must meet these two criteria:
    1) 0.6*Mw + MPi < MDL/1.5
    2) Mw + 0.4MPi < (MDL + MF)/2

   Mw = Destabilizing Wind Moment = 0 ft-lbf

   MPi = Destabilizing Moment about the Shell-to-Bottom Joint from Design «
                                                                   Pressure.
       = P*(PI*OD^2/4)*(144)*(OD/2)
       = 3*(3.1416*10^2/4)*(144)*(5)
       = 169,646 ft-lbf

   MDL = Stabilizing Moment about the Shell-to-Bottom Joint from the Shell and «
                                             Roof weight supported by the Shell.
       = (W_shell + W_roof)*OD/2
       = (2,520 + 656)*5
       = 15,880 ft-lbf

   tb = Bottom Plate thickness less C.A. = 0.1875 in.

   wl = Circumferential loading of contents along Shell-To-Bottom Joint.
      = 4.67*tb*SQRT(Sy_btm*H_liq)
      = 4.67*0.1875*SQRT(30,000*10)
      = 479.6 lbf/ft

   wl = 0.9 * H_liq * OD (lesser value than above)
      = 0.9*10*10
      = 90 lbf/ft

   MF = Stabilizing Moment due to Bottom Plate and Liquid Weight.
      = (OD/2)*wl*PI*OD
      = (5)(90)(3.1416)(10)
      = 14,137 ft-lbf

   Criteria 1
   0.6*(0) + 169,646 < 15,880/1.5
   Since 169,646 >= 10,587, Tank must be anchored.

   Criteria 2
   0 + 0.4 * 169,646 < (15,880 + 14,137)/2
   Since 67,858 >= 15,009, Tank must be anchored.

RESISTANCE TO SLIDING (per API-650 5.11.4)

     F_wind = vF * 18 * As
            = 0 * 18 * 100
            = 0 lbf
```

```
     F_friction = Maximum of 40% of Weight of Tank
          = 0.4 * (W_Roof_Corroded + W_Shell_Corroded +
                    W_Btm_Corroded + W_min_Liquid)
          = 0.4 * (656 + 2,520 + 674 + 0)
                = 1,540 lbf

     No anchorage needed to resist sliding since

        F_friction > F_wind
```

<Anchorage Requirement>
Anchorage required since Criteria 1, Criteria 2, or Sliding
are NOT acceptable.
Bolt Spacing = 10 ft, Min # Anchor Bolts = 6

SEISMIC MOMENT (API-650 APPENDIX E & API-620 APPENDIX L)

```
Ms   (Seismic Moment)
Ms = Z*I*(C1*Ws*Xs + C1*Wr*Ht + C1*W1*X1 + C2*W2*X2)

Z  = 0.075      Zone coefficient for zone 1 (from Table E-2)
I  = 1          Importance Factor
S  = 1.5        Site amplification factor (from Table E-3)

C1 = 0.6 = Lateral earthquake force coefficient

k  = 0.59  (factor for D/H = 1 from figure E-4)

T  = Natural Period of First Sloshing Mode
   = k*SQRT(OD) = 0.59*SQRT(10) = 1.866

C2 = Lateral Earthquake Force Coefficient
   = 0.75(S)/T = .75(1.5)/(1.866) = 0.6029

From Figures E-2 & E-3
X1_H = X1/H chart factor
X2_H = X2/H chart factor
W1_Wt = W1/Wt chart factor
W2_Wt = W2/Wt chart factor
Wt = Weight of tank contents @ Max. Liquid Level

X1 = (X1_H)*H = (0.4044)*10 = 4.0444
X2 = (X2_H)*H = (0.724)*10 = 7.2405
W1 = (W1_Wt)*Wt = (0.8132)*67,665 = 55,024
W2 = (W2_Wt)*Wt = (0.245)*67,665 = 16,578
Ws = W_shell + W_Insulation (New Condition)
   = 2,520 + 0 = 2,520
Wr = W_roof + Snow Load + W_Insulation (New Condition)
   = 656 + 1,634 + 0 = 2,290

C1*Ws*Xs = 0.6*(2,520)(5) = 7,560
C1*Wr*Ht = 0.6*(2,290)(10) = 13,740
C1*W1*X1 = 0.6*(55,024)(4.0444) = 133,523
C2*W2*X2 = (0.6029)(16,578)(7.2405) = 72,369

Ms = Z*I*(C1*Ws*Xs + C1*Wr*Ht + C1*W1*X1 + C2*W2*X2)
   = (0.075)(1)(7,560 + 13,740 + 133,523 + 72,369)
   = 17,039 ft-lbf

W_shell = Weight of Shell (New Condition)
W_roof2 = Weight of Roof Plates Supported By Shell (New)

wt = (W_shell + W_roof2)/(PI*OD)    (New Condition)
   = (2,520 + 656)/(PI*10)
   = 101. lbf/ft
```

RESISTANCE TO OVERTURNING (per Section E.4.1, E.4.2, assuming no anchors)

```
wl = 7.9*(tb1)*SQRT(Sy*G*H)
   = 7.9*(0.1875)*SQRT(36,000*1.39*10)
   = 1,048 lbf/ft

   where tb1 = t - CA = 0.1875 in. (for Bottom Plate)
```

1.25*G*H*OD = 1.25(1.39)(10)(10)
= 174 lbf/ft

since wl > 1.25*G*H*OD, wl = 1.25G*H*OD
wl = 174 lbf/ft

UNANCHORED TANKS (Section E.5.1)

Ms/[OD^2(wt+wl)] = 17,039/[(10^2)(101. + 174)] = 0.6194

b = wt + 1.273(Ms)/OD^2 = max longitudinal compressive force
= 101. + 1.273(17,039)/(10)^2 = 318 lbf/ft

MAXIMUM ALLOWABLE SHELL COMPRESSION (Section E.5.3)

b/(12t) = Max Longitudinal Compressive Stress
= 318/(12*(0.1875 - 0)) = 141 PSI

G*H*OD^2/t^2 = (1.39)(10)(10^2)/(0.1875 - 0)^2 = 39,538

Fa = 10^6*t/(2.5*OD) + 600*SQRT(G*H)
= (10^6)(0.1875 - 0)/(2.5*10) + (600)SQRT[(1.39)(10)]
= 9,737 PSI

t = 0.1875 - 0 = 0.1875 in. (OK since b/(12t) <= Fa)

ANCHORED TANKS (Section E.5.2)

b = wt + 1.273(Ms)/OD^2 = Max Longitudinal Compressive Force
= 101. + 1.273(17,039)/(10)^2 = 318 lbf/ft

MAXIMUM ALLOWABLE SHELL COMPRESSION (Section E.5.3)

b/(12t) = Max Longitudinal Compressive Stress
= 318/(12*(0.1875 - 0)) = 141 PSI

G*H*OD^2/t^2 = (1.39)(10)(10^2)/(0.1875 - 0)^2 = 39,538

Fa = 10^6*t/(2.5*OD) + 600*SQRT(G*H)
= (10^6)(0.1875 - 0)/(2.5*10) + (600)SQRT[(1.39)(10)]
= 9,737 PSI

t = 0.1875 - 0 = 0.1875 in. (OK since b/(12t) <= Fa)

ANCHORAGE OF TANKS (Section E.6.1)

N = 8 Number of Anchors
D = 10.3333 ft Diameter of Anchor Circle

Net_Uplift = Net uplift due to internal pressure

MAR = minimum anchorage resistance due to seismic moment
= 1.273(Ms)/OD^2 + Net_Uplift/Circumference
= 1.273(17,039)/10^2 + 30,753/(PI*10)
= 1,196 lbf/ft circumference

btseis = anchor tension req'd to resist seismic moment
= MAR*D*PI/(N)
= (1,196)(10.3333)(PI)/(8) = 4,853 lbf

ANCHOR BOLT DESIGN

```
   Bolt Material : A-193 Gr B7
                   Sy = 105,000 PSI

< Uplift Load Cases, per API-650 Table 5-21b >

   D  (tank OD) = 10 ft
   P  (design pressure) = 83.14 INCHES H2O
   Pt (test pressure per F.7.6) = 1.25 * P = 103.93 INCHES H2O
   Pf (failure pressure per F.6) = N.A. (see Uplift Case 3 below)
   t_h (roof plate thickness) = 0.1875 in.
   Mw (Wind Moment) = 0 ft-lbf
   Mrw (Seismic Ringwall Moment) = 17,039 ft-lbf
   W1 (Dead Load of Shell minus C.A. and Any
       Dead Load minus C.A. other than Roof
       Plate Acting on Shell)

   W2 (Dead Load of Shell minus C.A. and Any
       Dead Load minus C.A. including Roof
       Plate minus C.A. Acting on Shell)

   W3 (Dead Load of New Shell and Any
       Dead Load other than Roof
       Plate Acting on Shell)

   For Tank with Self Supported Roof,
   W1 = Corroded Shell + Shell Insulation
      = 2,520 + 0
      = 2,520 lbf
   W2 = Corroded Shell + Shell Insulation + Corroded
        Roof Plates + Roof Dead Load
      = 2,520 + 0
        + 656 + 11,762 * 8.0325/144
      = 3,832 lbf
   W3 = New Shell + Shell Insulation
      = 2,520 + 0
      = 2,520 lbf

   Uplift Case 1: Design Pressure Only
      U = [(P - 8*t_h) * D^2 * 4.08] - W1
      U = [(83.14 - 8*0.1875) * 10^2 * 4.08] - 2,520
        = 30,789 lbf
      bt = U / N = 3,849 lbf

      Sd = 15,000 PSI
      A_s_r = Bolt Root Area Req'd
      A_s_r = bt/Sd
            = 3,849/15,000 = 0.257 in^2

   Uplift Case 2: Test Pressure Only
      U = [(Pt - 8*t_h) * D^2 * 4.08] - W1
      U = [(103.93 - 8*0.1875) * 10^2 * 4.08] - 2,520
        = 39,271 lbf
      bt = U / N = 4,909 lbf
```

```
    Sd = 20,000 PSI
    A_s_r = Bolt Root Area Req'd
    A_s_r = bt/Sd
          = 4,909/20,000 = 0.245 in^2

Uplift Case 3: Failure Pressure Only
  Not applicable since if there is a knuckle on tank roof,
  or tank roof is not frangible.
  Pf (failure pressure per F.6) = N.A.

Uplift Case 4: Wind Load Only
   PWR = Wind_Uplift/5.208
       = 0/5.208
       = 0 IN. H2O
   PWS = vF * 18
       = 0 * 18
       = 0 lbf/ft^2
   MWH = PWS*(D+t_ins/6)*H^2/2
       = 0*(10+0/6)*10^2/2
       = 0 ft-lbf
   U = PWR * D^2 * 4.08 + [4 * MWH/D] - W2
     = 0*10^2*4.08+[4*0/10]-3,832
     = -3,832 lbf
   bt = U / N = -479 lbf

   Sd = 0.8 * 105,000 = 84,000 PSI
   A_s_r = Bolt Root Area Req'd
   A_s_r = N.A., since Load per Bolt is zero.

Uplift Case 5: Seismic Load Only
   U = [4 * Mrw / D] - W2*(1-0.4*Av)
   U = [4 * 17,039 / 10] - 3,832*(1-0.4*0)
     = 2,984 lbf
   bt = U / N = 373 lbf

   Sd = 0.8 * 105,000 = 84,000 PSI
   A_s_r = Bolt Root Area Req'd
   A_s_r = bt/Sd
         = 373/84,000 = 0.004 in^2

Uplift Case 6: Design Pressure + Wind Load
   U = [(0.4*P + PWR - 8*t_h) * D^2 * 4.08] + [4 * MWH / D] - W1
     = [(0.4*83.14+0-8*0.1875)*10^2 * 4.08]+[4*0 / 10] - 2,520
     = 10,436 lbf
   bt = U / N = 1,305 lbf

   Sd = 20,000 = 20,000 PSI
   A_s_r = Bolt Root Area Req'd
   A_s_r = bt/Sd
         = 1,305/20,000 = 0.065 in^2

Uplift Case 7: Design Pressure + Seismic Load
   U = [(0.4*P - 8*t_h)*D^2 * 4.08] + [4*Mrw/D] - W1*(1-0.4*Av)
   U = [(0.4*83.14-8*0.1875)*10^2*4.08]+[4*17,039/10]-2,520*(1-0.4*0)
     = 17,252 lbf
   bt = U / N = 2,157 lbf
```

```
      Sd = 0.8 * 105,000 = 84,000 PSI
      A_s_r = Bolt Root Area Req'd
      A_s_r = bt/Sd
            = 2,157/84,000 = 0.026 in^2

   Uplift Case 8: Frangibility Pressure
     Not applicable since if there is a knuckle on tank roof,
     or tank roof is not frangible.
     Pf (failure pressure per F.6) = N.A.
```

< ANCHOR BOLT SUMMARY >

```
   Bolt Root Area Req'd = 0.257 in^2

   d = Bolt Diameter = 1 in.
   n = Threads per inch = 8
   A_s = Actual Bolt Root Area
       = 0.7854 * (d - 1.3 / n)^2
       = 0.7854 * (1 - 1.3 / 8)^2
       = 0.5509 in^2

   Exclusive of Corrosion,
   Bolt Diameter Req'd = 0.702 in. (per ANSI B1.1)

   Actual Bolt Diameter = 1.000 in.

   Bolt Diameter Meets Requirements.
```

<ANCHORAGE REQUIREMENTS>

```
   Minimum # Anchor Bolts = 6
   NOTE: API-620 has no minimum spacing requirement, but
      per API-650 5.12.3, maximum spacing is 10 ft if anchorage required.

Actual # Anchor Bolts = 8
Anchorage Meets Spacing Requirements.
```

CAPACITIES and WEIGHTS

Maximum Capacity (to upper TL)	:	17,514 gal
Design Capacity (to Max Liquid Level)	:	29,195 gal
Minimum Capacity (to Min Liquid Level)	:	0 gal
NetWorking Capacity (Design - Min.)	:	29,195 gal

	New Condition	Corroded
Shell	2,520 lbf	2,520 lbf
Roof Plates	656 lbf	656 lbf
Bottom	674 lbf	674 lbf
Stiffeners	0 lbf	0 lbf
Nozzle Wgt	0 lbf	0 lbf
Misc Roof Wgt	0 lbf	0 lbf
Misc Shell Wgt	0 lbf	0 lbf
Insulation	0 lbf	0 lbf
Total	3,850 lbf	3,850 lbf

Weight of Tank, Empty	:	3,850 lbf
Weight of Tank, Full of Product (SG=1.39)	:	71,577 lbf
Weight of Tank, Full of Water	:	52,575 lbf
Net Working Capacity	:	5,839 gal
Foundation Area Req'd	:	79 ft^2
Foundation Loading, Empty	:	48.73 lbf/ft^2
Foundation Loading, Full of Product (SG=1.39)	:	906.04 lbf/ft^2
Foundation Loading, Full of Water	:	665.51 lbf/ft^2

SURFACE AREAS
Roof 82 ft^2
Shell 314 ft^2
Bottom 79 ft^2

Wind Moment 0 ft-lbf
Seismic Moment 17,039 ft-lbf

MISCELLANEOUS ATTACHED ROOF ITEMS

MISCELLANEOUS ATTACHED SHELL ITEMS

MAWP & MAWV SUMMARY FOR Y08-125

MAXIMUM CALCULATED INTERNAL PRESSURE

```
     MAWP = 15 PSI or 415.7 IN. H2O (per API-620)

     MAWP = Maximum Calculated Internal Pressure (due to shell)
          = 15 PSI or 415.7 IN. H2O

     MAWP = Maximum Calculated Internal Pressure (due to roof)
            (Roof also Per F.1.3 and F.7.5.c)
          = 15 PSI or 415.7 IN. H2O

  TANK MAWP = 15 PSI or 415.7 IN. H2O
```

MAXIMUM CALCULATED EXTERNAL PRESSURE

```
     MAWV = Maximum Calculated External Pressure (due to shell)
          = -1.8721 PSI or -51.88 IN. H2O

     MAWV = Maximum Calculated External Pressure (due to roof)
          = -4.549 PSI or -126.07 IN. H2O

     MAWV = Maximum Calculated External Pressure (due to bottom plate)
          = -0.248 PSI or -6.87 IN. H2O

  TANK MAWV = -0.248 PSI or -6.87 IN. H2O
```

IV. C. TANK SUPPORT CALCULATIONS

LAPD Tank Support Calcs

rev. 04-28-11

These calculations are for the LAPD tank support platform.

The LAPD tank is a flat bottom atmospheric tank built to API 620 standards. The tank is designed for the tank bottom to be supported.

Argon Data at 84K Saturation Temperature

Argon physical properties from NIST REPROP

argon liquid density

$\rho_{ArL} := 1385 \cdot \frac{kg}{m^3}$ $\qquad \rho_{ArL} = 86.46 \cdot \frac{lb}{ft^3}$

LAPD Tank Dimensions and data

$D := 10 \cdot ft \qquad H := 10 \cdot ft$

$Tank_{vol} := 6506 \cdot gal$

$Tank_{vol} = 24.63 \cdot m^3$

This volume is for liquid full, which includes the domed top. ref: Midwest Steel Fabricators, drawing Y08-125.

Weight of argon for liquid full

$Argon_{wt} := Tank_{vol} \cdot \rho_{ArL} \qquad Argon_{wt} = 34110\,kg \qquad Argon_{wt} = 75199 \cdot lb$

Tank wall data - 7 gage stainless plate

$Plate_{wt} := 7.88 \cdot \frac{lb}{ft^2} \qquad Plate_{wt} = 38.47 \cdot \frac{kg}{m^2}$

The tank walls and top are fabricated from 7 ga. 304 SS.

$Plate_{th} := 0.1793 \cdot in$

Area of tank metal

$$Area_{SS} := 2\pi \cdot \left(\frac{D}{2}\right) \cdot H + \pi \left(\frac{D}{2}\right)^2 + 1.3 \cdot \pi \cdot \left(\frac{D}{2}\right)^2$$

Metal area for side, bottom and top of tank.

$Area_{SS} = 494.80 \cdot ft^2$ $\quad$ $Area_{SS} = 45.97 \cdot m^2$

Weight of tank metal

A generous 1000 lb allowance is used to cover nozzles, nozzle extensions and instruments attached to the tank.

$Tank_{wt} := Area_{SS} \cdot Plate_{wt} + 1000 \cdot lb$ $\quad$ $Tank_{wt} = 4899 \cdot lb$ $\quad$ $Tank_{wt} = 2222 \cdot kg$

Trymer 2000 Density

$Insul2000_{dens} := 33 \cdot \frac{kg}{m^3}$

Insulation thickness

$Insul2000_{thk} := 5 \cdot 2 \cdot in + 0.75 \cdot in$ $\quad$ $Insul2000_{thk} = 10.75 \cdot in$

ref: Trymer 2000, Form T2000XP1-041210, ITW Insulation Systems,
and Insulation and Tank Support Drawing ME466366

Estimate of Insulation Volumes
Used to determine insul. weight attached to tank

$$V_{insul.side} := \pi \cdot \left(\frac{D + 2Insul2000_{thk}}{2}\right)^2 \cdot H - \pi \cdot \left(\frac{D}{2}\right)^2 \cdot H$$

$V_{insul.side} = 8.68\, m^3$

$$V_{insul.top} := \pi \cdot \left(\frac{D + 2Insul2000_{thk}}{2}\right)^2 \cdot Insul2000_{thk}$$

$V_{insul.top} = 2.77\, m^3$

$$Insul_{wt} := Insul2000_{dens} \cdot \left(V_{insul.side} + V_{insul.top}\right) = 378\, kg$$

Check of Tank Load on Plywood

The platform has to hold the maximum weight of a liquid full insulated argon tank. A generous 500 lb allowance is used to cover mastic and plywood.

Total Tank Weight on platform

$Total_{tk.wt} := Tank_{wt} + Insul_{wt} + Argon_{wt} + 500 \cdot lb$

$Total_{tk.wt} = 36937 kg$ $\quad$ $Total_{tk.wt} = 81431 \cdot lb$

Platform Load per unit area from tank

$$Platform_{loading} := \frac{Total_{tk.wt} \cdot g}{\pi \cdot \left(\frac{D}{2}\right)^2}$$

$Platform_{loading} = 49.6 \cdot kPa$ $\quad$ $Platform_{loading} = 7.20 \cdot psi$

The first layer on the platform is 3/4" plywood sheeting

Plywood Allowable Compression Perpendicular to face (adjusted for load duration in excess of 10 years)

The plywood is 3/4" sheathing, APA rated exposure 1 or 2 of Grade Stress Level 3 or better.

$Plywood_{comp} := 90\% \cdot 1100 \cdot psi$

$Plywood_{comp} = 6826 \cdot kPa$

This is for S3, face grade 2, per APA - The Engineered Wood Association. Adjusted per APA Plywood Design Specification (1997) paragraph 3.3.1.2.

The tank load is less than the plywood allowable compression stress.

Check of Tank Load on Trymer 6000 under plywood

$$Plywood_{loading} := \frac{Total_{tk.wt} \cdot g}{\pi \cdot \left(\frac{D}{2}\right)^2}$$

$Plywood_{loading} = 49.64 \cdot kPa$ $\quad$ $Plywood_{loading} = 7.20 \cdot psi$

Trymer 6000, rigid insulation is the layer below the plywood.

Trymer 6000 Compression Strength Perpendicular to face

$Trymer6000_{comp} := 140 \cdot psi$

$Trymer6000_{comp} = 20160 \cdot \frac{lbf}{ft^2}$

ref: Trymer 6000, Form T600001-0209,
ITW Insulation Systems.

$Trymer6000_{comp} = 965 \cdot kPa$

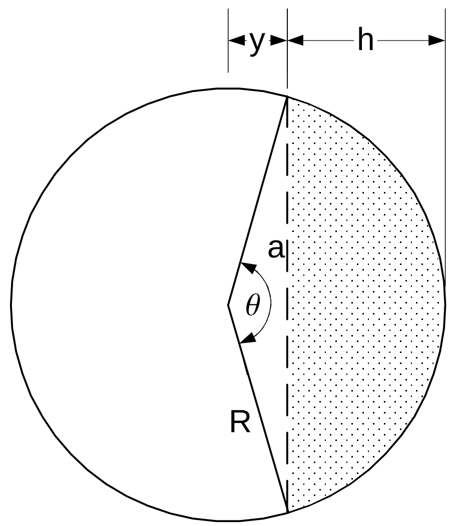
$$\frac{Plywood_{loading}}{Trymer6000_{comp}} = 5.14 \cdot \%$$

The tank load distributed through the plywood is less than 6% of the Trymer 6000 compression stress.

Load Distribution between railcar and cribbing

More than half the tank rests on the railcar. These calculations determine what that distribution is based on the tank support detail in drawing 3942.000-ME-466366.

$$R := \frac{D}{2}$$



$$h := R - \left(\frac{96 \cdot in}{2} - 17.75 \cdot in\right) = 2.48 \cdot ft$$

$$a := 2 \cdot \sqrt{h \cdot (2 \cdot R - h)}$$

$$Segment_{area} := R^2 \cdot acos\left(\frac{R - h}{R}\right) - (R - h) \cdot \sqrt{2 \cdot R \cdot h - h^2}$$

$$Segment_{area} = 1.41 \cdot m^2$$

ref: http://mathworld.wolfram.com/CircularSegment.html

$$cribbing_{share} := \frac{Segment_{area}}{\pi \cdot \left(\frac{D}{2}\right)^2} = 19.32 \cdot \%$$

$$railcar_{share} := 1 - cribbing_{share} = 80.68 \cdot \%$$

Check of Tank Load on Platform Under Trymer 6000

Trymer 6000 Density

$Insul6000_{dens} := 96 \cdot \frac{kg}{m^3}$

Insulation thickness

$Insul6000_{thk} := 3 \cdot 3 \cdot in$ $\quad Insul6000_{thk} = 9 \cdot in$

Weight of Trymer 6000 base

An allowance of 8" all around is provided to cover trymer 6000 platform which is wider than the tank with wall insulation.

$$base6000_{wt} := \pi \cdot \left(\frac{D + 2Insul2000_{thk} + 2 \cdot 8 \cdot in}{2} \right)^2 \cdot Insul6000_{thk} \cdot Insul6000_{dens}$$

$base6000_{wt} = 275.85\,kg$

A 500 lb allowance is included to cover the weight of bolting, mastic, etc

Load carried by Railcar

$rail_{load} := \left(Total_{tk.wt} + base6000_{wt} + 500 \cdot lb \right) \cdot railcar_{share}$

$rail_{load} = 30206 \cdot kg$ $\quad rail_{load} = 66592 \cdot lb$

This rail load is further distributed over 2 railcars with a 1.5" steel plate spanning the railcars. These railcars were originally designed to carry electro-magnets. The combined carrying capacity of 2 of these railcars is in excess of 150,000 pounds per Jim Kilmer. For comparison, the 2 wheel assemblies from a typical boxcar carry minimum of 70 tons.
(ref: http://www.worldtraderef.com/WTR_site/Rail_Cars/Guide_to_Rail_Cars.asp)

The rail load is less than the railcar capacity.

Check of Cribbing Under Trymer 6000

Load carried by Cribbing

A 500 lb allowance is included to cover the weight of bolting, mastic, etc

$crib_{load} := \left(Total_{tk.wt} + base6000_{wt} + 500 \cdot lb\right) \cdot cribbing_{share}$

$crib_{load} = 7234 \cdot kg$ $\qquad crib_{load} = 15947 \cdot lb$

Plastic Lumber Allowable Compression Perpendicular to face (utility grade plastic lumber)

$Plastic_{lumber.comp} := 1420 \cdot psi \qquad Plastic_{lumber.comp} = 9790555 \cdot Pa$

ref: Plastic Lumber Engineering Properties, Plastic Lumber Yard, http://plastic lumberyard.com/electricaldata.htm (accessed 09/16/10)

The first length of plastic lumber is assumed to be 12" from rail car steel plate.

$plastic_{lumber.L} := 2 \cdot \sqrt{(h + 12 \cdot in) \cdot [2 \cdot R - (h + 12 \cdot in)]} \qquad plastic_{lumber.L} = 9.53 \cdot ft$

$plastic_{lumber.A} := plastic_{lumber.L} \cdot 5.5 \cdot in = 4.37 \cdot ft^2$

$plastic_{lumber.loading} := \frac{crib_{load} \cdot g}{plastic_{lumber.A}} = 175 \cdot kPa$

$plastic_{lumber.loading} = 25.36 \cdot psi$

The first section of plastic lumber can handle the load. The additional sections just further reduce the load per unit area.

Gaps between the plastic lumber and the trymer base are bridged with 2x4 construction lumber and plywood sheeting.

Dry Pine Lumber Allowable Compression Perpendicular to face (adjusted for greater than 10 year load duration)

$pine_{comp} := 90\% \cdot 3000 \cdot kPa = 392 \cdot psi$

ref:Wood Handbook - Wood as an Engineering Material, Forest Products Laboratory, 2010, General Technical Report FPL-GTR-190.

$Plywood_{comp} = 6826 \cdot kPa$

The actual loading is less than the pine lumber and plywood compression capacity, even if only one length of support is used.

Minimum number of cross lumber support members

Cross members of plastic lumber are used in the cribbing.

$$Min_{cross.A} := \frac{crib_{load} \cdot g}{Plastic_{lumber.comp}} = 11.2 \cdot in^2$$

A single cross member provides 3.5"x3.5" of area, 11.9 sq in. Additional cross members just further reduce the distributed load.

The first long section of plastic lumber and wood lumber have compressive strength in excess of the loading from the tank. There are actually several more rows of cribbing support, which further reduce the distributed load.

Check of Cribbing support span

The trymer 6000 tank base will experience some deflection over the open spans between cribbing supports. The deflection is estimated by treating the open span of trymer 6000 as a simple beam with uniform load distribution. The plywood sandwiching the trymer 6000 is ignored. The maximum span determines the number of cribbing support rows.

Spacing between Cribbing supports - open span

$span_L := 12 \cdot in$ MAX.

Trymer moment of inertia - at longest open span

$$I := \frac{span_L \cdot Insul6000_{thk}^{3}}{12} = 0.03516 \cdot ft^4$$

Total load on open Span of Trymer 6000

$$W := Plywood_{loading} \cdot span_L \cdot h = 25207.3\, m \cdot s^{-2.0} \cdot lb$$

Trymer 6000 flexural modulus (modulus of elasticity)

$$E := 5800 \cdot \frac{lb}{in^2}$$

$$\Delta_b := \frac{5}{384} \cdot \frac{W \cdot span_L^{3}}{E \cdot I} = 0.1341\, m \cdot s^{-2} \cdot in$$

ref: Machinery's Handbook, 28th ed,pages, 236 and 258.

The trymer 6000 deflection is minimal, even at a 12 inch span length. The actual span length will be less than 12 inches.

Minimum # of cribbing rows under trymer 6000 (using 90% of max span to provide additional safety margin)

$$min_{crib.rows} := \frac{h}{90 \cdot \% \cdot span_L} = 2.8$$

A minimum of 3 cribbing support rows will be used under the trymer 6000

IV. D. ANCHOR BOLT CALCULATIONS

LAPD Tank Anchor Bolt Calc's

rev. 05-02-11

These calculations are for the LAPD tank anchor bolts.

The tank uplift value comes from the vendor calculations. The vendor basic uplift check calculations identify that a minimum of 6 anchors are needed. The tank vendor designed the tank with 8 anchor points.

Anchor Points

There are 8 anchor points that will be held down by 3/4"-10 threaded SS rod.

ref: Insulation and Tank Support Drawing ME466366

$N_{anchors} := 8$

Anchor Bolt Data

$Bolt_{yield.str} := 10020 \cdot lbf$

for 3/4"-10 304 or 316 SS rod
ref: Bolt Supply House, Rod Data.

$Area_{tensile} := 0.334 \cdot in^2$

Net Uplift due to Design Pressure on Empty Tank

$Net_{uplift} := 30753 \cdot lbf$

ref: Midwest Imperial Steel Calculations, p 21 of 33 (vendor page number).

Load Per Anchor Bolt (from uplift)

$$Load_{per.bolt} := \frac{Net_{uplift}}{N_{anchors}} = 3844.1 \cdot lbf$$

$load_{seismic} := 4853 \cdot lbf$

This is the anchor tension required to resist seismic moment, per the vendor calculations. The seismic moment is the larger load.

$$\frac{load_{seismic}}{Bolt_{yield.str}} = 48.4 \cdot \%$$

Bolt load is less than 50% of its yield strength.

Bolt Stress

$$Bolt_{stress} := \frac{load_{seismic}}{Area_{tensile}} = 14529.9 \cdot psi$$

For comparison, this is less than the 15,000 psi allowable anchor bolt stress per API 650 table 5.21b.

Two of the anchor points are anchored to the floor using 3/4" Hilti HDI drop-in anchors.

The following notes are for these two anchor points.

Hilti Anchor maximum Tension

$$HILTI_{ult.tension} := 14125 \cdot lbf$$

ref:HILTI HDI drop-in anchor technical guide, section 4.3.8, page 362.

The Hilti maximum tension value is interpolated from the Hilti data for concrete having 3500 psi compressive stress. This is the conservative value recommended by Tom Lackowski of FESS for the PC4 concrete floor.

$$\frac{load_{seismic}}{HILTI_{ult.tension}} = 34.4 \cdot \%$$

Hilti anchor load is less than 35% of its ultimate strength.

IV. E. FEA MODEL OF EMPTY TANK INTERNAL PRESSURE TEST

June 6, 2011

Mechanical Analysis of LAr Tank Pressure Test

Bob Wands

Introduction and Summary

The LAr tank will be tested at an internal pressure of 3.75 psi. Because the bottom plate is very thin, it will tend to push downward against the vessel insulation and the asymmetric rail car/cribbing support on which the vessel rests, while simultaneously reacting this force by pulling upward on the combination of rail car and concrete to which it is bolted. The purpose of this analysis is to determine the likely mechanical behavior of the vessel/insulation/supports, and identify any aspects which require remediation.

The results show that the outer edges of the rail cars to which the tank is bolted may, if not constrained, rise approximately 5 inches during the test. This displacement imposes unacceptable strains on the insulation. To reduce this deformation, it is recommended that the outer corners of the cars be anchored to the concrete floor. Analysis suggests that this solution requires an anchor system capable of resisting approximately 2200 lbs of force, and results in a large reduction in tank and insulation deformations.

The actual installation does not provide access to the corners of both rail cars. One car must be constrained approximately 34 inches from the corner. The force developed in this constraint is estimated at 3500 lbs.

A simple system of 1x6 in steel plates, welded to the platform column flanges, is proposed as a means of providing rail car constraints.

The FE Model

The finite element model is shown in Fig. 1. The tank and rail cars are steel with an elastic modulus of 29e6 psi; the insulation under the tank is Trymer 3000 XP polyisocyanurate foamed plastic with an elastic modulus of 1200 psi and a maximum compressive strength of 65 psi (see Appendix I). The insulation is split into three layers horizontally. Within a given layer, several individual blocks are used. The precise modeling of the individual blocks was not attempted, though the three layers were included.

The tank is supported on two rail cars which cover about 75% of the bottom area, and wooden cribbing that covers the remainder. The rail cars are simulated as a 1.5 inch steel plate resting on two steel rails. The tank bolts to the rail cars in six locations, and in two locations, anchors directly to the concrete floor.

In establishing symmetry boundary conditions, the rail car boundary, and the insulation boundary were not included, since these boundaries correspond to discontinuities (cuts in the insulation, and the physical edge of the rail car) and cannot contribute to the model stiffness as continuous structures could.

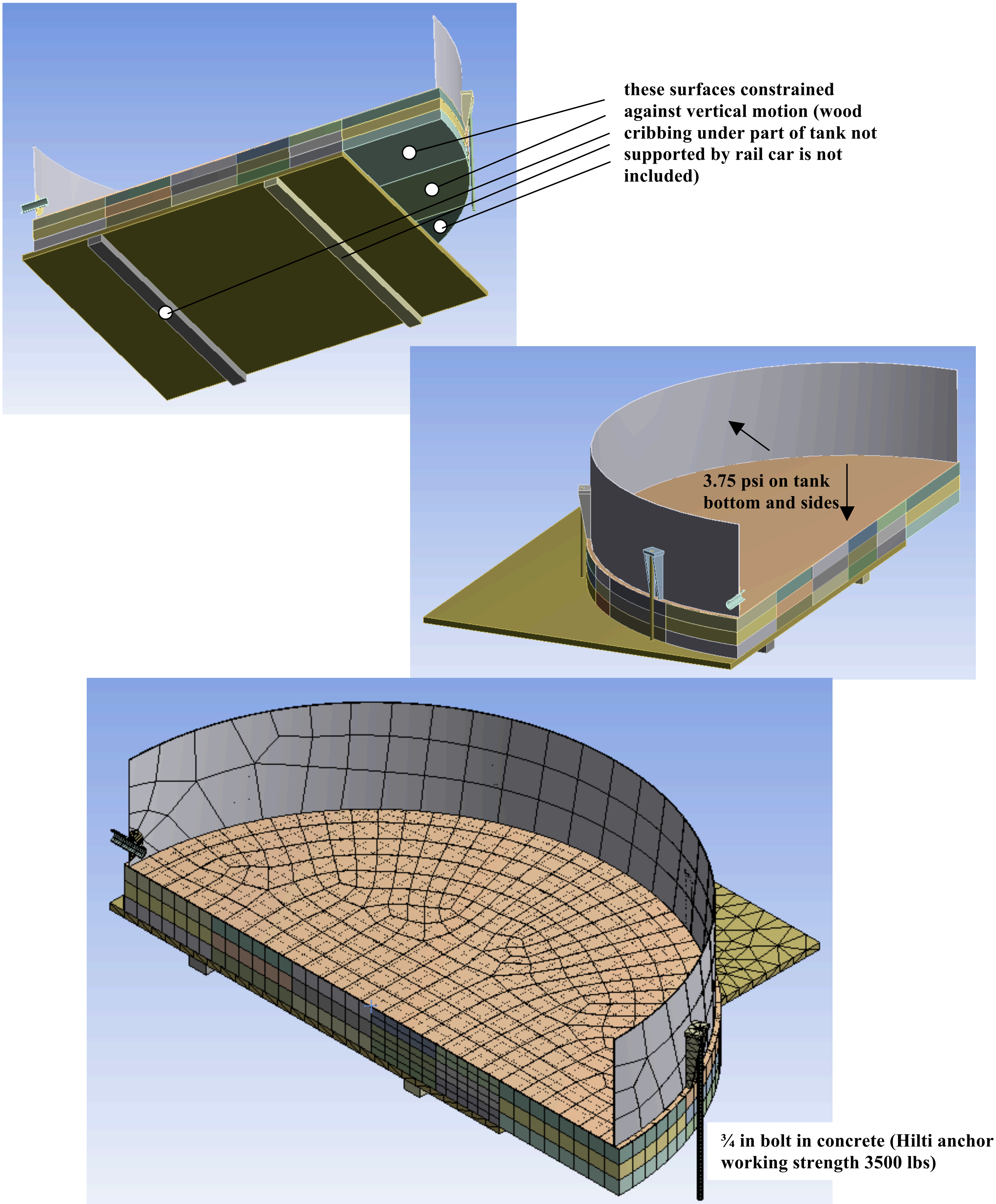


Figure 1. FE model for tank/railcar simulation

The model allows the rail car plate, each layer of insulation, and the tank bottom to separate from any surfaces that they are initially in contact with.

The pressure load of 3.75 psi is applied to the bottom of the tank, and the inside surface of the cylindrical shell. The shell is truncated, so it is necessary to include the equilibrating vertical pressure force from the missing tank portion by applying a vertical force at the cylindrical shell cut. The weight of the rail car and insulation is not included in the model, as a conservatism, though the tank weight (appr. 2400 lbs) is reflected by reducing the equilibrating vertical force.

Results

The model was first run with no external constraint on the outer corners of the rail car. The resulting deformations are shown in Figs. 2 and 3. The unconstrained rail car plate lifts entirely off one of the “rails,” reacting in its final position with the end of the other rail, the stack of insulation and wood not supported by the rail car, and the bolt which is anchored to the concrete floor.

Maximum vertical deflections are over five inches at the rail car corner, and the resulting force on the concrete anchor bolt is about 2000 lbs.

The model was then modified to include a constraint at the outer corner of the rail car. The resulting deformations are shown in Figs. 4 and 5. The rail car plate remains in contact with both rails, and overall deflections are substantially reduced.

The force required to constrain the corner of the rail car is 2200 lbs.

Stresses in the tank and support assembly, and compressive stresses in the insulation under the tank bottom, are shown in Figs. 6 and 7, respectively. The stresses in the tank bottom are low; the stresses in the cylindrical shell are highest near the cut boundary, which was not simulated with the intent of accurate stress determination (the shell extends several feet further vertically), but in any case do not exceed 13 ksi. The insulation stresses are a maximum of -17 psi, which is less than the Trymer’s maximum compressive stress in that direction of -65 psi.

While constraining the corner will work on one rail car, the constraint for the other car can be applied no closer than about 34 inches from the corner. Figs. 8 and 9 show the vertical deformation of all components, and the vertical deformation of the tank bottom only. Deformations are somewhat higher than those obtained with corner constraints.

The resulting force to constrain this rail car at this location is 3500 lbs.

Constraining the rail car increases the force on the ¾ in bolts in the concrete. The maximum occurs for the case of constraint 34 in. from the corner, and is 3400 lbs, which is below the allowable force of 3500 lbs.

Stresses in the tank and support assembly, and compressive stresses in the insulation, are shown in Figs. 10 and 11. Tank stresses are somewhat higher than for the corner constraint case, and insulation compressive stress rises slightly. But both stresses are within the limits of the materials.

The model was originally intended to be truly symmetric. However, when the inability to reach one corner of a car was discovered, and the need to perform another analysis with a constraint 34 inches from the corner became clear, the symmetry (now false) was retained for expedience. A subsequent modification to a full model showed no significant difference in the constraint force values obtained from the two "symmetric" models.

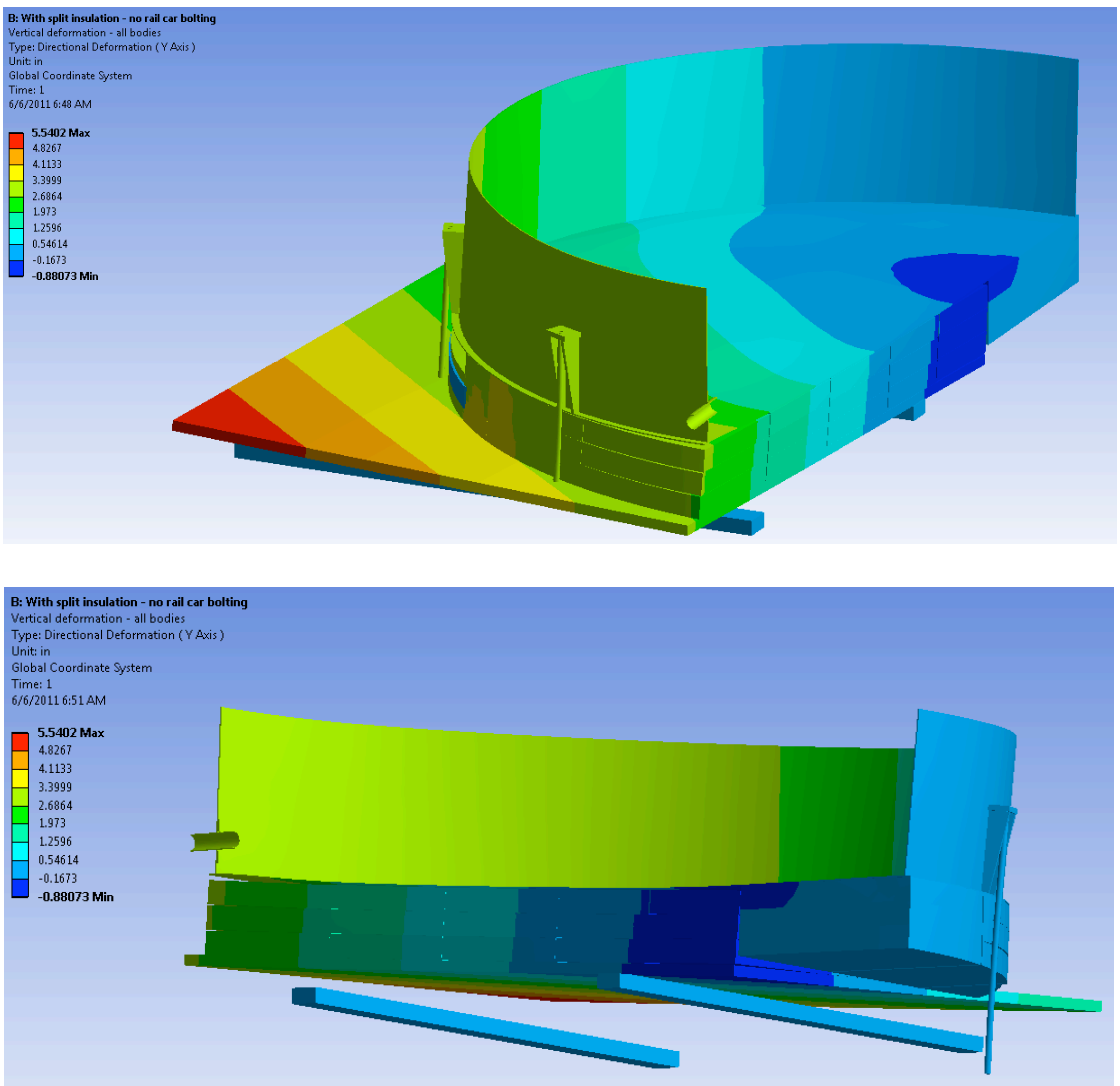


Figure 2. Vertical Deformation – no constraint on railcar

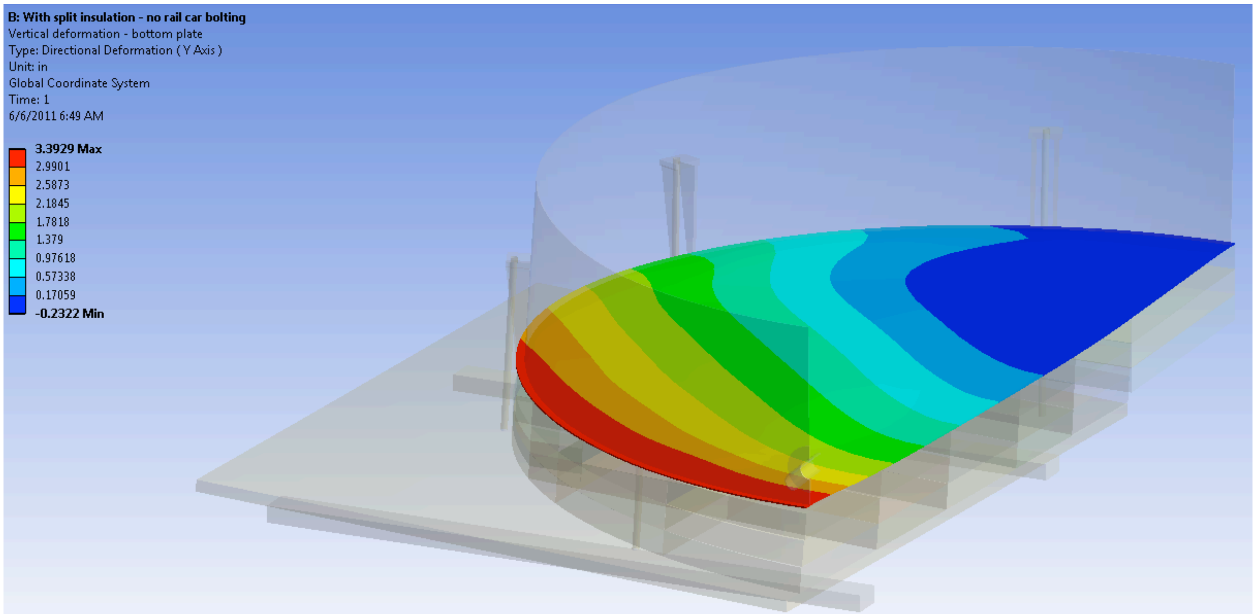


Figure 3. Vertical deformation of tank bottom – no constraint on railcar

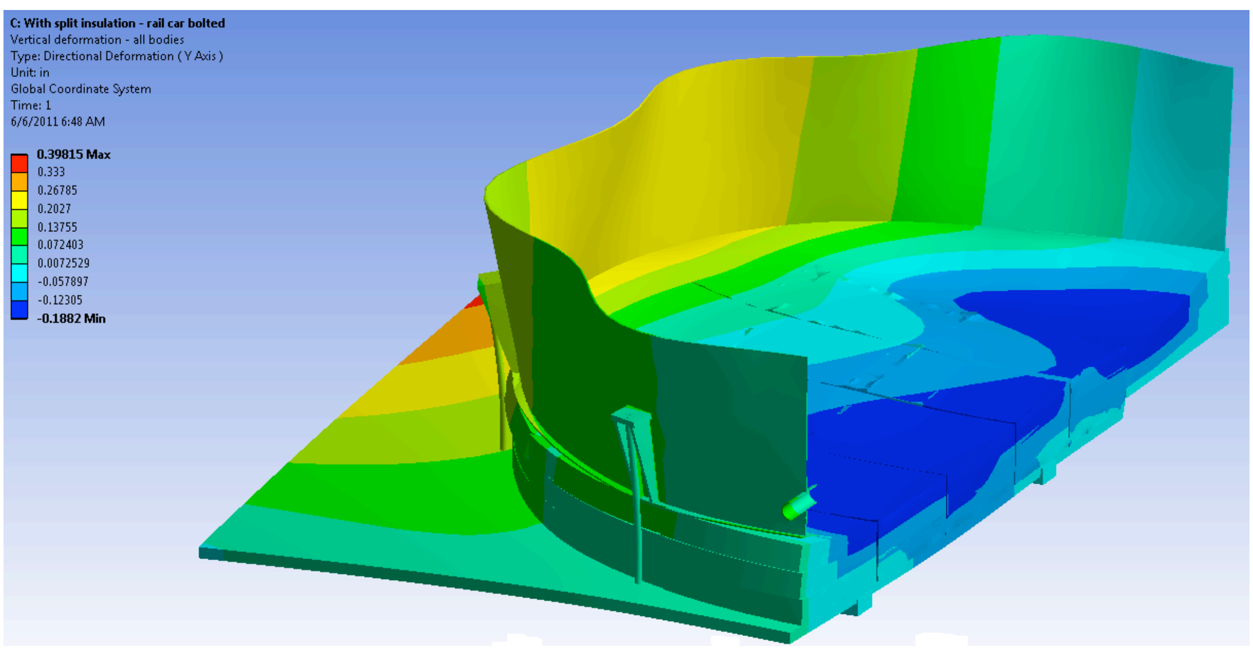


Figure 4. Vertical Deformation – Railcar constrained at corner

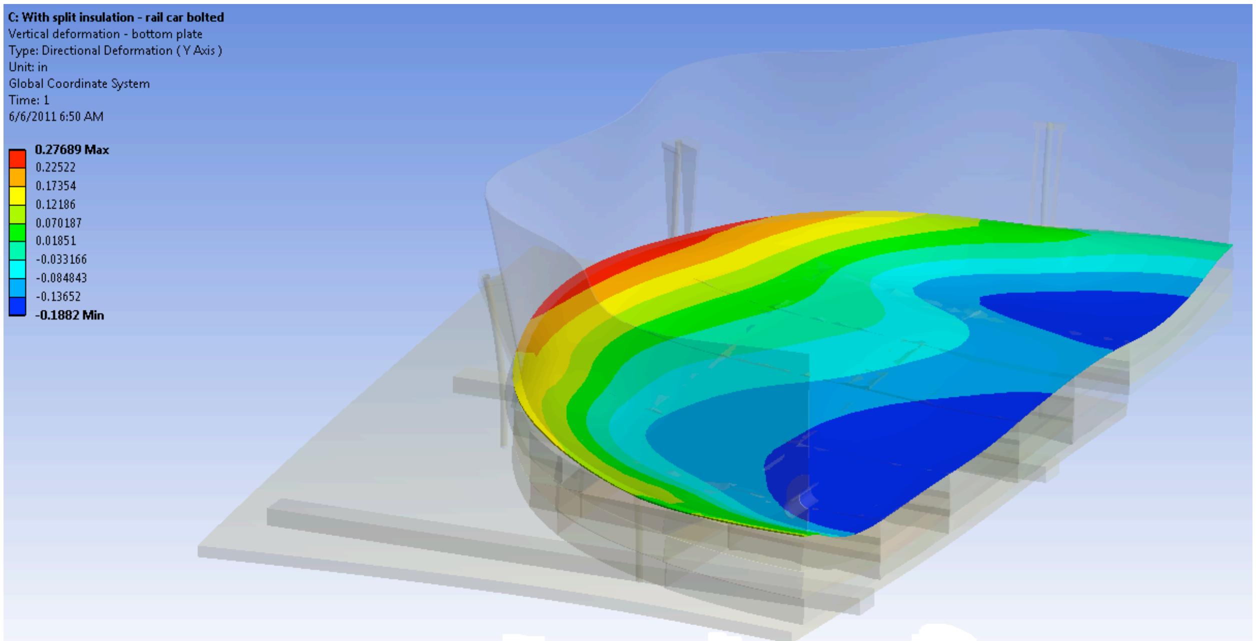


Figure 5. Vertical deformation of tank bottom – railcar constrained at corner

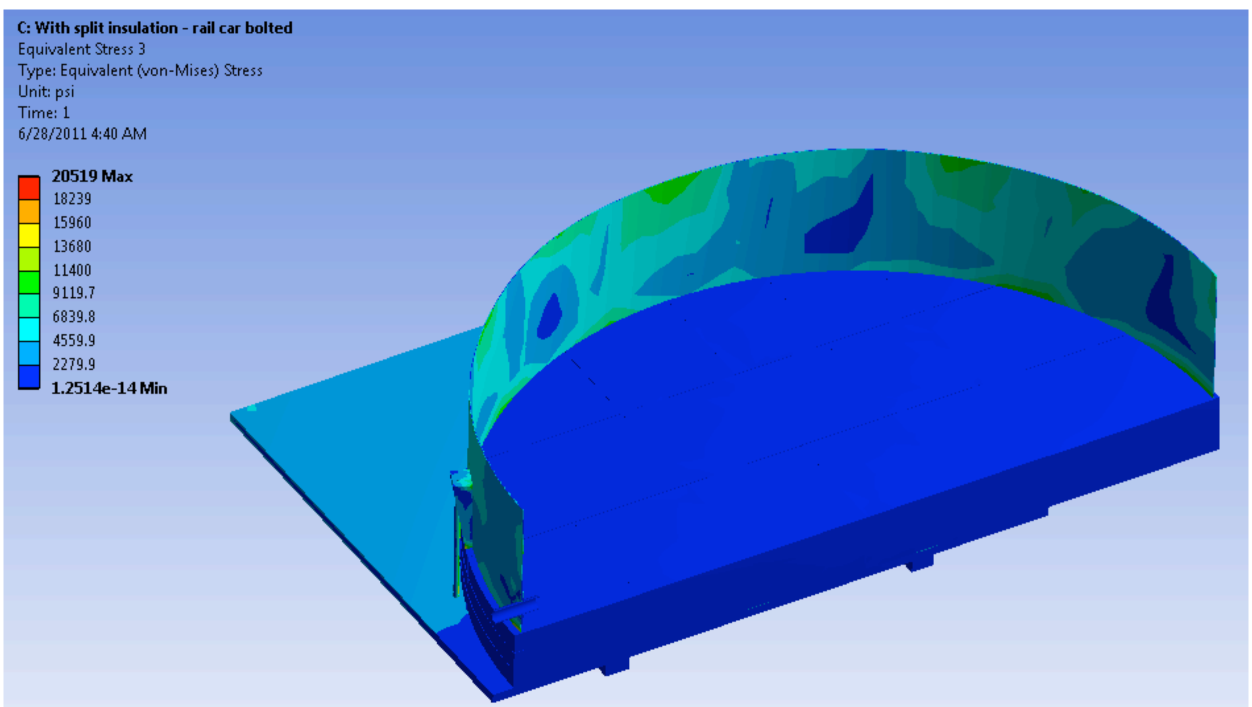


Figure 6. Stresses in assembly – railcar constrained at corner

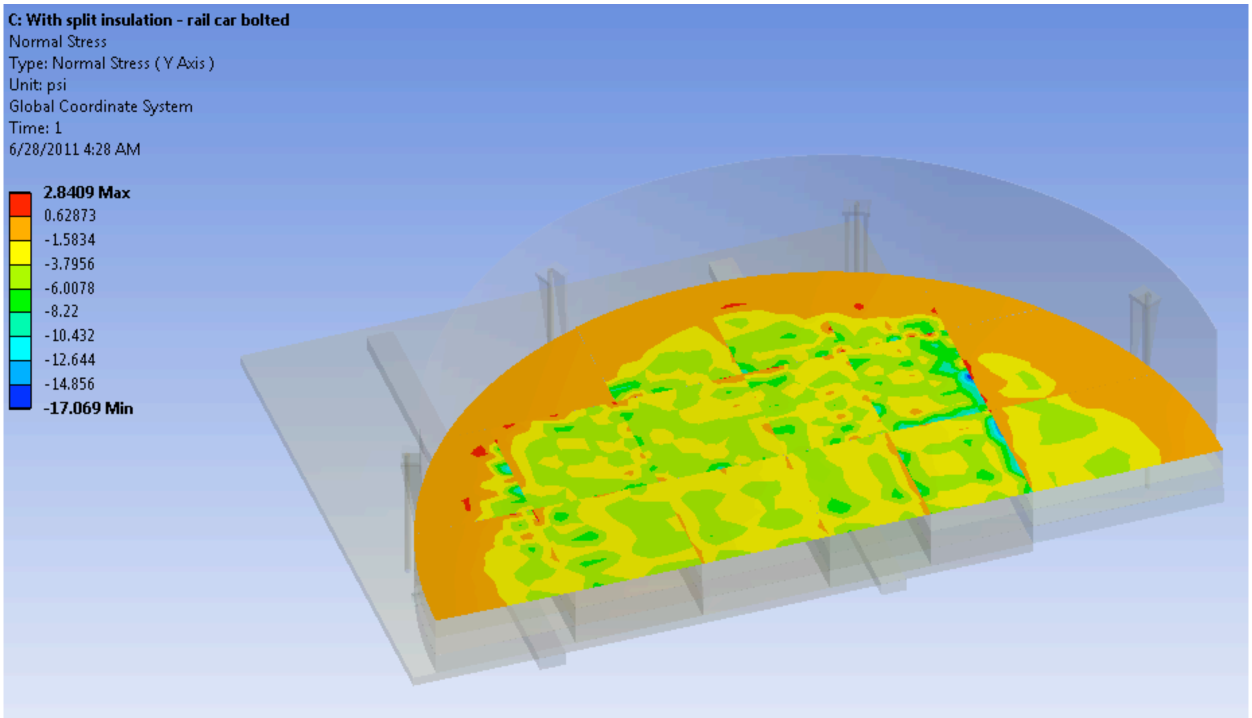


Figure 7. Compressive stresses in insulation – railcar constrained at corner

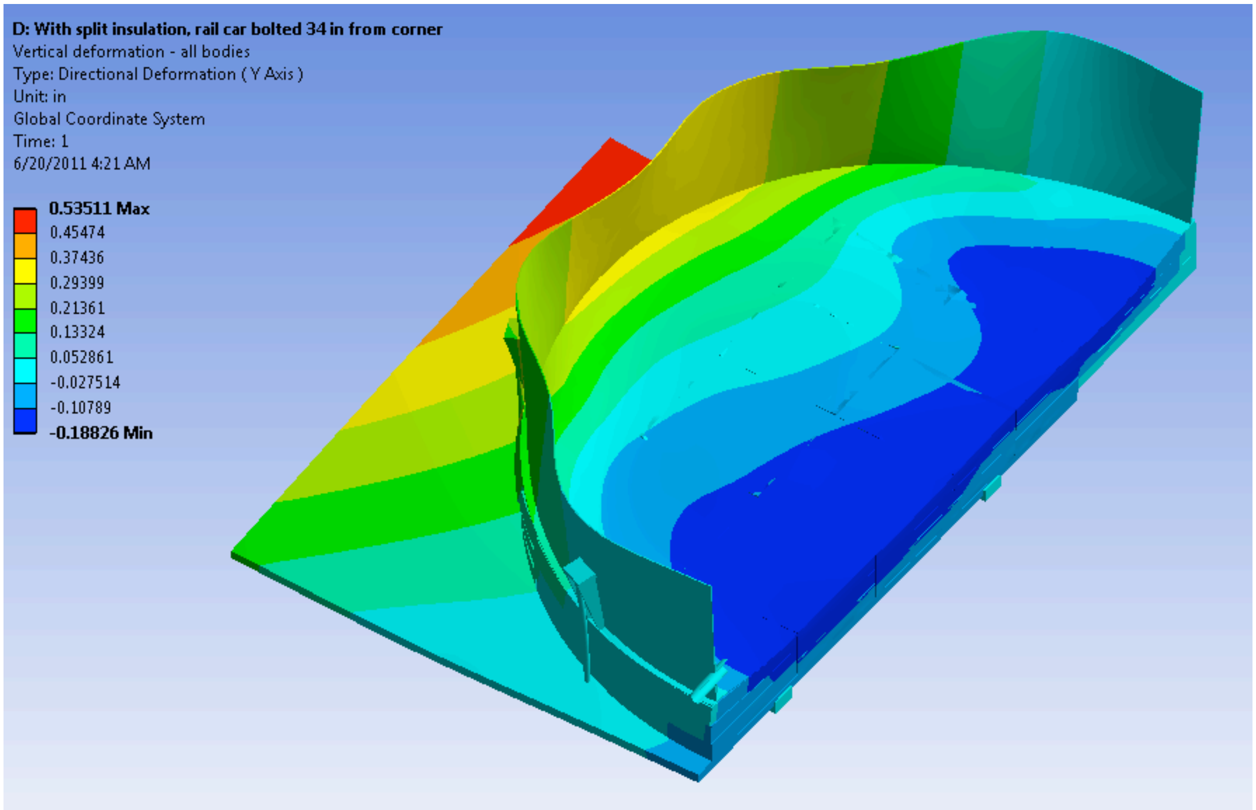


Figure 8. Vertical Deformation – Railcar constrained 34 inches from corner

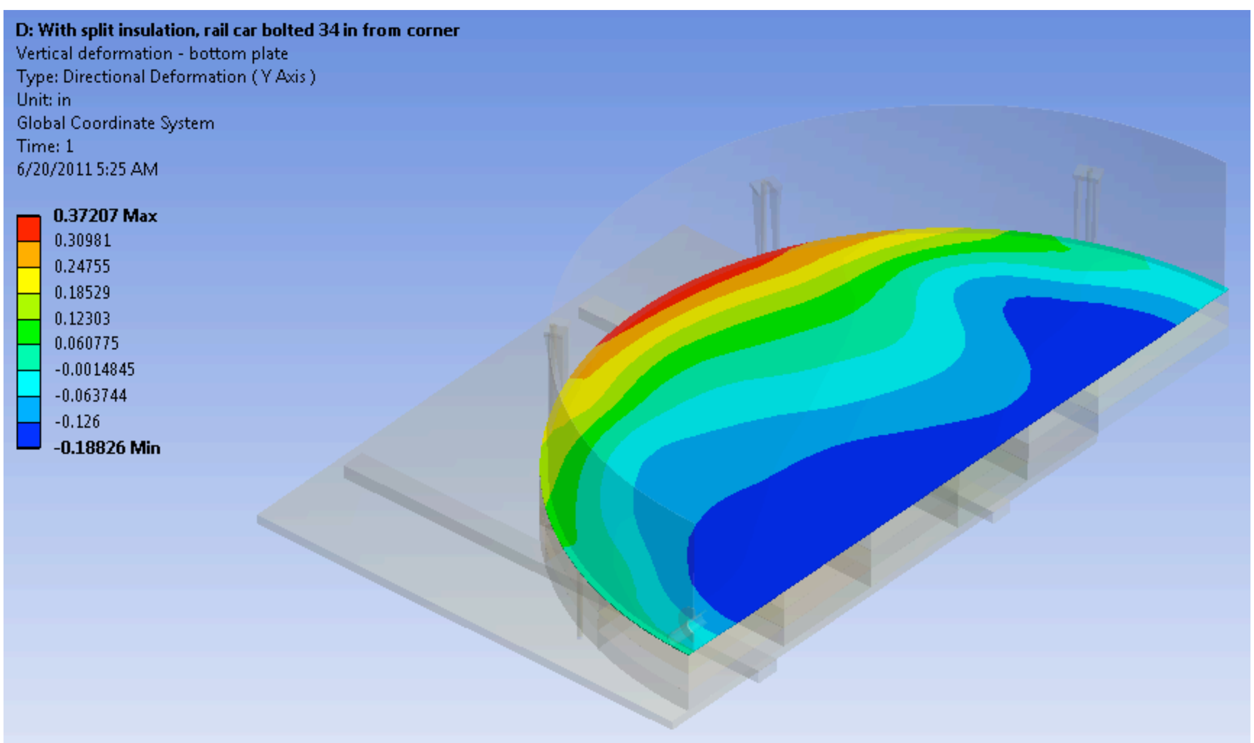


Figure 9. Vertical Deformation of bottom plate – Railcar constrained 34 inches from corner

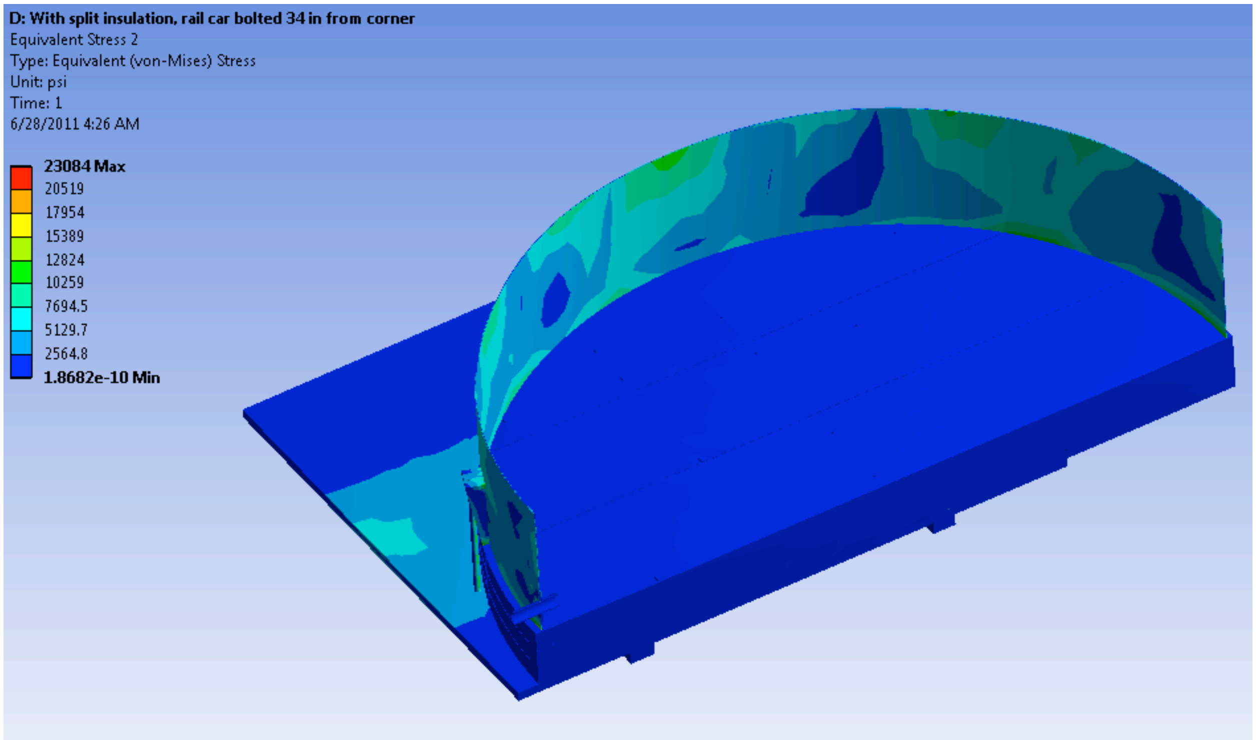


Figure 10. Stresses in assembly – Railcar constrained 34 inches from corner

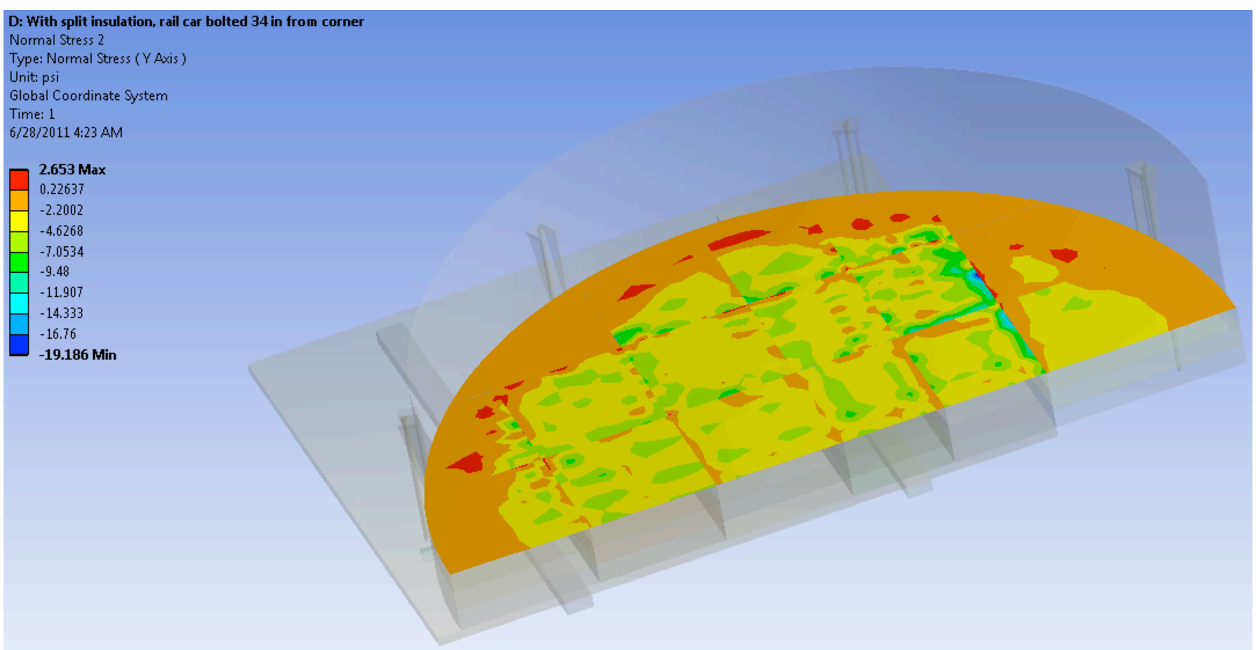


Figure 11. Compressive stresses in insulation – Railcar constrained 34 inches from corner

Structure to Constrain the Rail Cars

The concrete strength of the floor is uncertain, and there are several seams near the rail car corners and edges. For this reason, it was decided to provide the constraint with a structure which welds to the flanges of the existing W8x24 platform columns.

A source of concern when placing the vertical reaction on the columns is the quality of the four 5/8 in Hilti concrete anchors which fix the base of a column to the floor. For the rail car constrained at the corner, the corresponding column has Hiltis which provide the necessary edge distance (distance from seams) to develop their full strength. The maximum operating load on these anchors is 2680 lbs (derated from the catalog load for 4000 psi concrete to correspond to 3500 psi concrete).

For the rail car requiring support 34 inches from the corner, the corresponding column has two Hilti anchors (those nearest the cart) which are within 4 inches of a concrete seam. Hilti derates the capacity at a 5 inch edge distance by a factor of 0.8. No derating is given for less than 5 inches. For the purposes of this analysis, it is assumed that working loads of 1000 lbs per anchor are admissible. The final design of the support, however, should actually allow failure of the two weak Hiltis, while not overloading the two remaining.

The support for the rail car constrained at the corner is shown in Fig. 12. It is a single 1x6 plate, welded on one side to each flange of the column. The maximum concrete anchor load is 2540 lbs, which is less than the maximum working load of 2680 lbs.

The support for the rail car constrained 34 inches from the corner is shown in Fig. 13. Again, 1x6 in plate is used, but in this case two plates are welded to each side of the column, but only to the flange furthest from the cart. The plates extend 26 inches beyond the flange, and interact with the floor. If all anchors remain active, the weak Hiltis are under a load of 560 lbs, while the full-strength Hiltis are under a load of 1740 lbs. If the weak anchors fail, the load on the full-strength Hiltis increases to 2300 lbs, which is still below the maximum operating load of 2680 lbs.

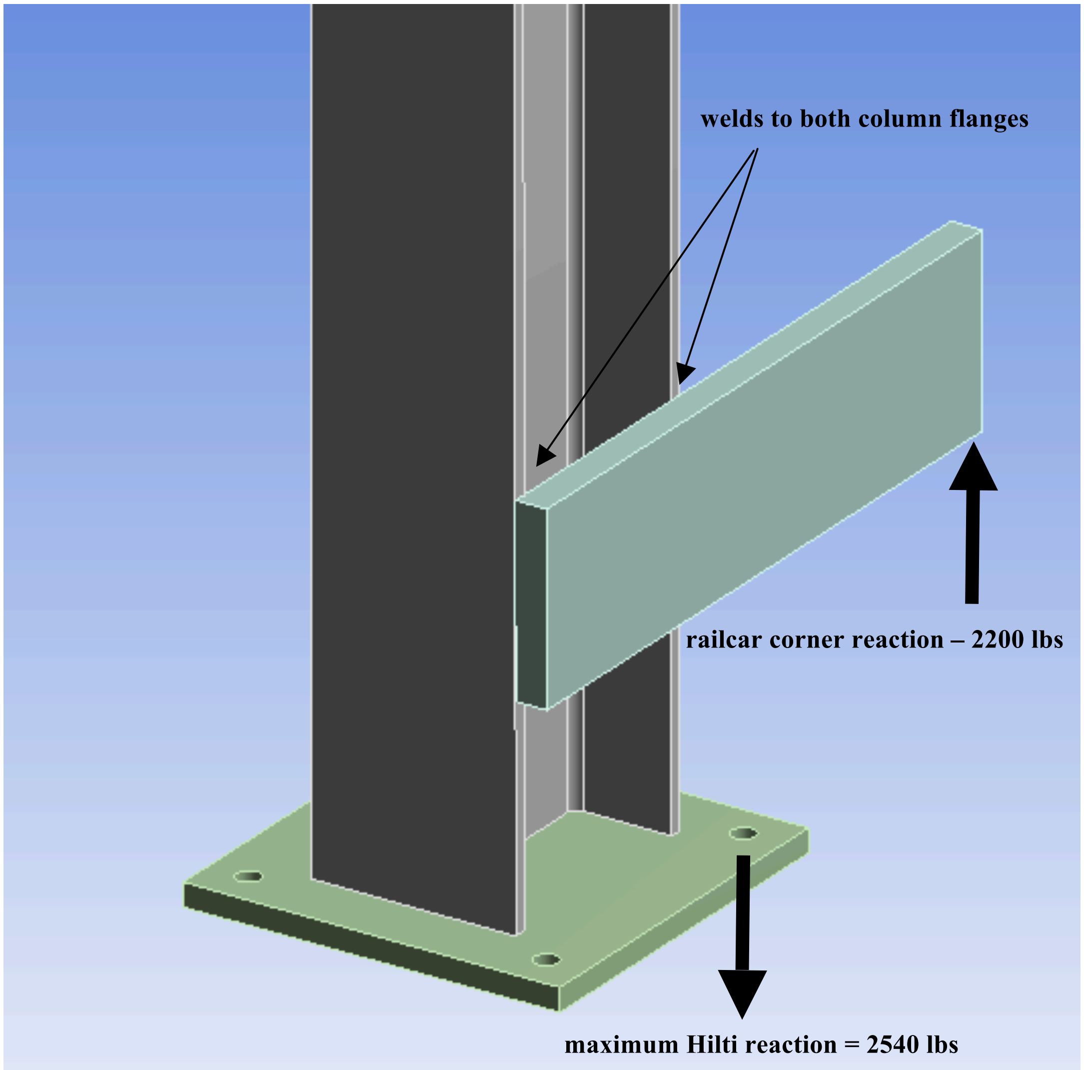


Figure 12. Single 1x6 support for rail car corner constraint

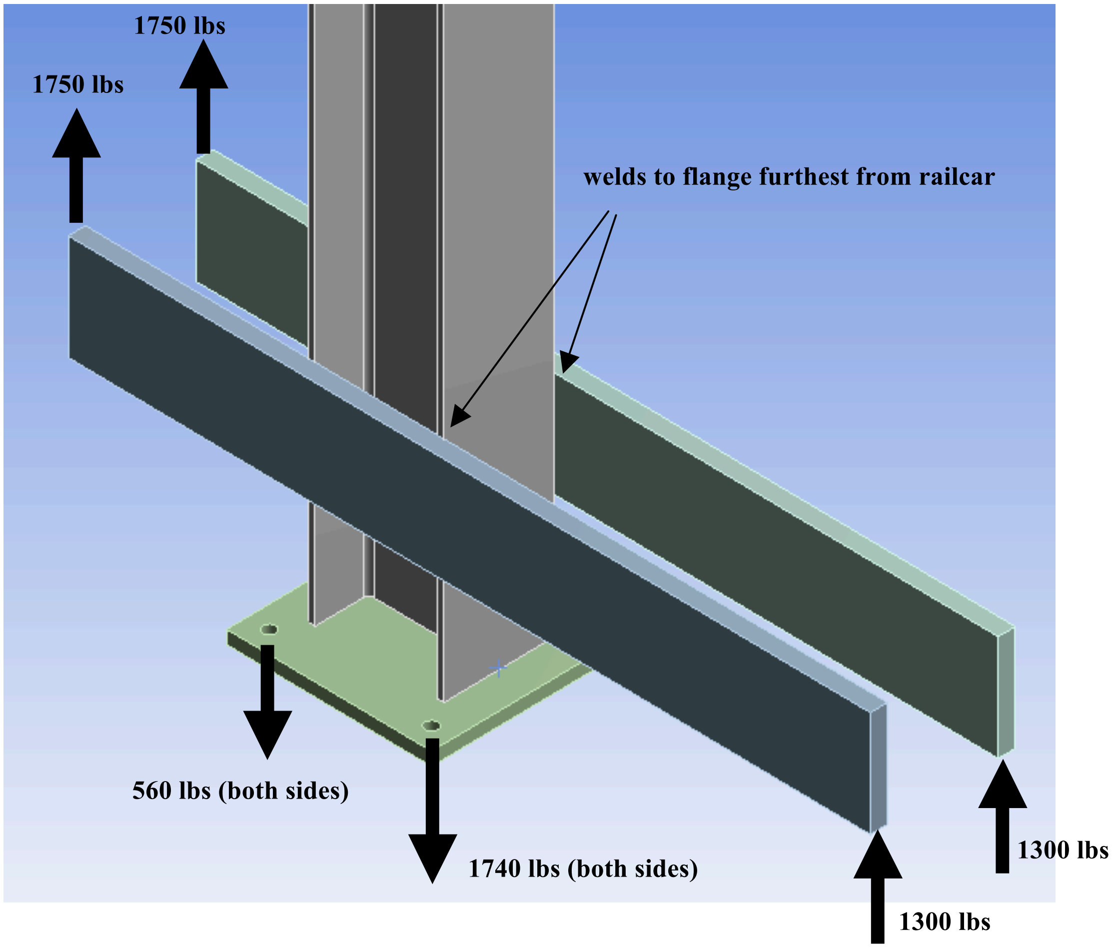


Figure 13. Double 1x6 support for railcar constraint 34 inches from corner

Additional Rail Car Constraints

The maximum calculated vertical deformation of the tank bottom plate when the two outer corners of the railcars are constrained is approximately 0.37 in (see Fig. 9). To reduce the deformation further, the remaining accessible corner of each car was also constrained.

To simulate this condition, a full model was created. The resulting bottom plate deformations from this model are shown in Fig. 14. They have been reduced by a factor of approximately four.

For the railcar with two constraints at the corners, the new corner constraint develops a reaction of 1300 lbs. For the car constrained 34 inches from the corner, the new corner constraint develops a reaction of 1600 lbs. The original corner constraint reactions fall substantially, from 3500 lbs to 2500 lbs for the constraint 34 inches from the corner, and from 2200 lbs to 1800 lbs for the car constrained at the corner. This is additional safety margin on the original constraints (those attached to the columns).

The additional constraints use a vertical load path from the corner down to the concrete (see Figs. 15). The vertical members are attached to the concrete with a ¾ in Hilti with a maximum working load 3500 lbs. This is much greater than the maximum load of 1600 lbs which the most heavily loaded of these additional constraints may see.

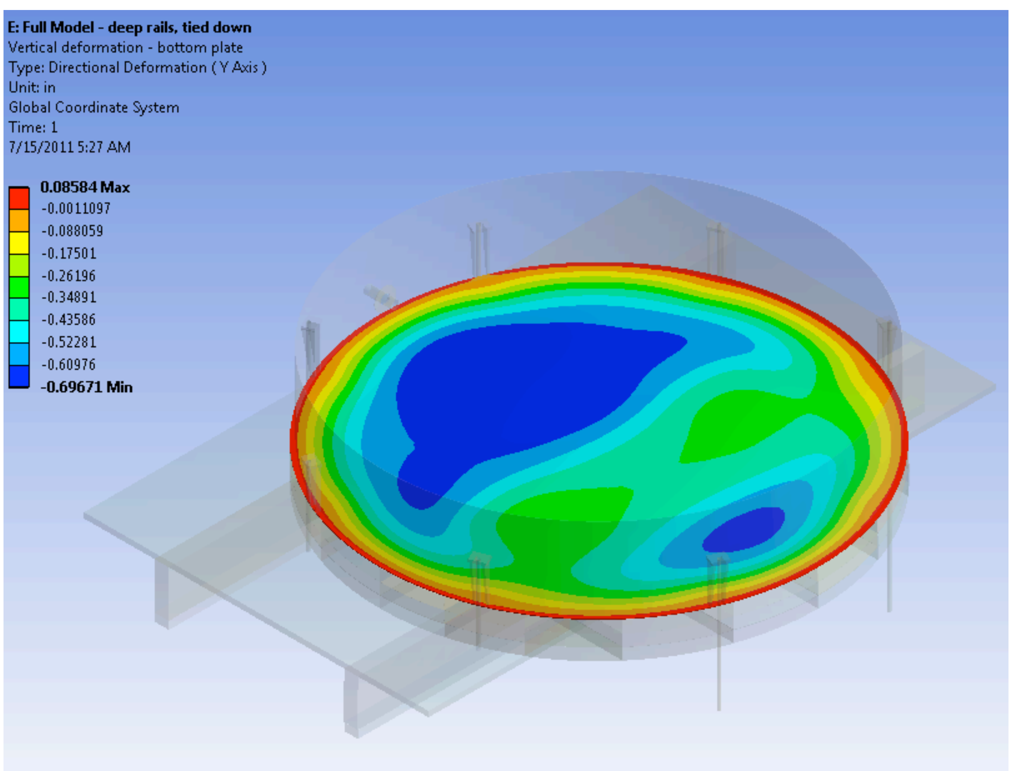
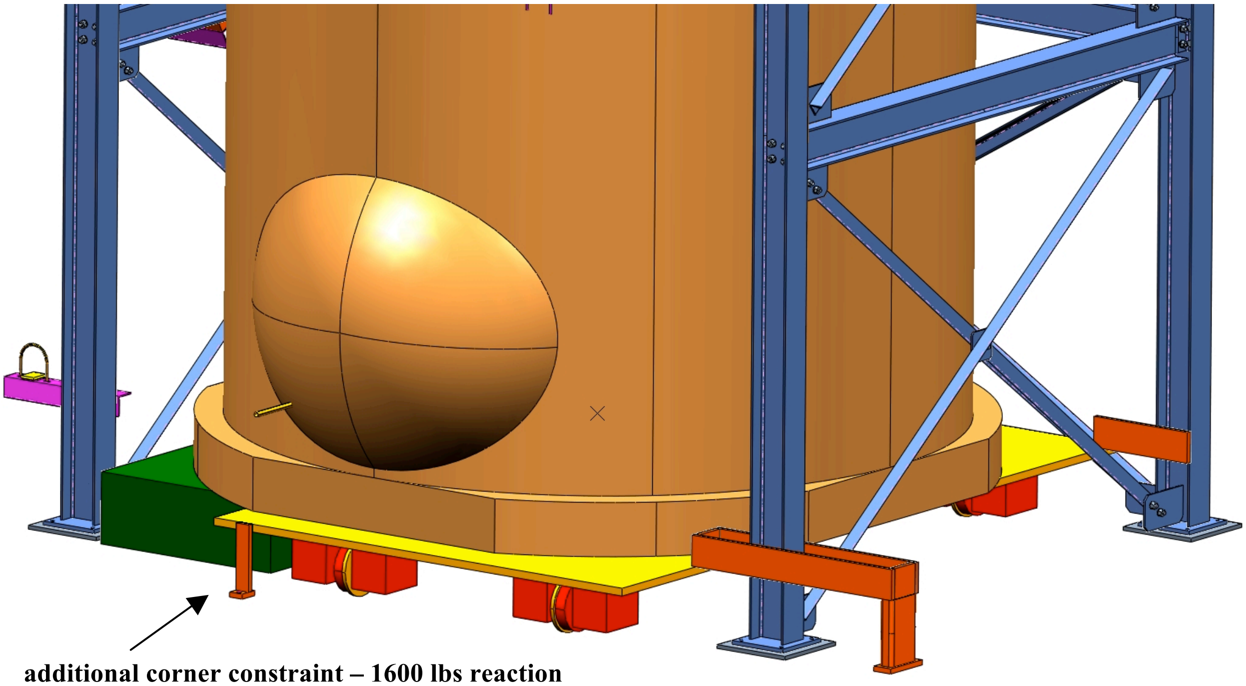


Figure 14. Vertical Deformation of bottom plate – two additional rail car constraints at corners



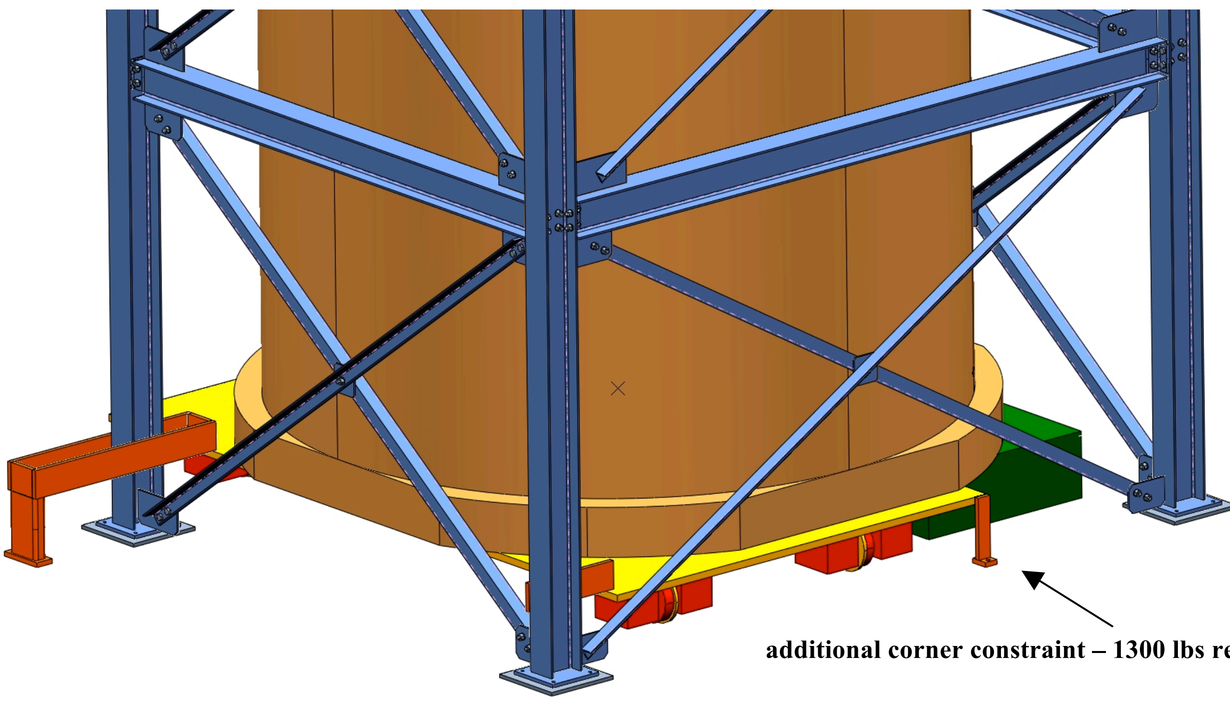


Figure 15. Additional corner constraints on the rail cars

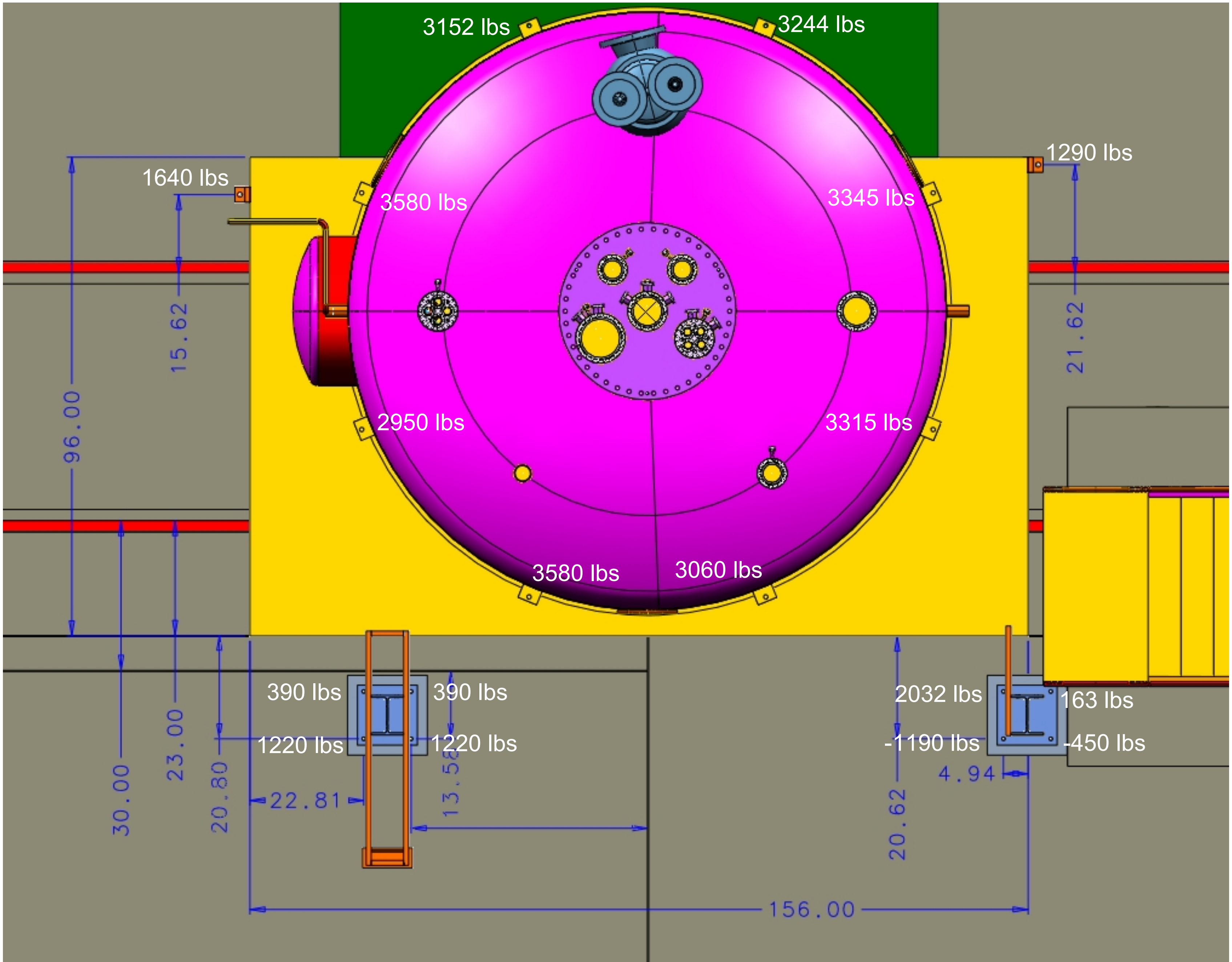


Figure 16: Reactions at threaded tie downs

Appendix I. Insulation Properties

Product Information

TRYMER™ 3000 complies with ASTM C591, Grade 2, Type III

TABLE 1

Physical Properties of TRYMER™ 3000 Polyisocyanurate Insulation

Property[1] and Test Method[2]	Value
Density[3], ASTM D1622, lb/ft³ (kg/m³)	3 (48.0)
Compressive Strength[3], ASTM D1621, lb/in² (kPa)	
Parallel to rise – thickness	65 (450)
Perpendicular to rise – width	45 (310)
Perpendicular to rise – length	55 (380)
Compressive Modulus, ASTM D1621, lb/in² (kPa)	
Parallel to rise – thickness	1,200 (8,270)
Perpendicular to rise – width	800 (5,500)
Perpendicular to rise – length	1,200 (8,270)
Shear Strength, ASTM C273, lb/in² (kPa) Parallel and perpendicular, avg	25 (172)
Shear Modulus, ASTM C273, lb/in² (kPa) Parallel and perpendicular, avg	375 (2,600)
Tensile Strength, ASTM D1623, lb/in² (kPa) Parallel to rise – thickness	40 (275)
Flexural Strength, ASTM C203, lb/in² (kPa) Parallel to rise	60 (413)
Flexural Modulus, ASTM C203, lb/in² (kPa) Parallel to rise	1,230 (8,480)
k-factor, ASTM C518, Btu•in/hr•ft²•°F (W/m•°C) Aged 180 days @ 75°F (24°C)	0.19 (0.027)
R-Value[4]/in., ASTM C518, hr•ft²•°F/Btu (m²•°C/W) Aged 180 days @ 75°F (24°C)	5.3 (0.93)
Closed Cell Content, ASTM D2856, %, min.	95

Property[1] and Test Method[2]	Value
Water Absorption, ASTM C272, 24-hr immersion, % by volume	<0.7
Water Vapor Permeability, ASTM E96, perm-inch (ng/Pa•s•m)	3 (4.6)
Dimensional Stability[3],[5], ASTM D2126	
At -40°F (-40°C), 7 days	
Length, % change	-0.2
Volume, % change	-0.2
At -10°F (-23°C), 7 days	
Length, % change	0.2
Volume, % change	0.2
At 158°F (70°C), 7 days	
Length, % change	1.5
Volume, % change	3.0
At 158°F (70°C)/97% R.H., 7 days	
Length, % change	1.0
Volume, % change	2.4
At 300°F (149°C), 7 days	
Length, % change	1.4
Volume, % change	2.0
Service Temperature[6], °F (°C)	-297 to +300 (-183 to +149)
Surface Burning Characteristics[7], ASTM E84 Flame Spread/Smoke Developed (FS/SD)	25/450 up to 6" (15 cm) thickness
Color	Tan

(1) All properties are measured at 74° (23°C), unless otherwise indicated.

(2) Unless otherwise indicated, data shown are typical values obtained from representative production samples. This data may be used as a guide for design purposes, but should not be construed as specifications. For property ranges and specifications, consult your ITW representative.

(3) Average value through insulation cross section.

(4) R means resistance to heat flow. The higher the R-value, the greater the insulating power.

(5) Frequent and severe thermal cycling can produce dimensional changes significantly greater than those stated here. Special design consideration must be made in systems that cycle frequently.

(6) Above 300°F (149°C), discoloration and charring will occur, resulting in an increased k-factor in the discolored area.

(7) This numerical flame spread data is not intended to reflect hazards presented by this or any other material under actual fire conditions.

- **For Technical Information: 1-800-231-1024**
- **For Sales Information: 1-800-231-1024**
- ITW Insulation Systems
- 1370 East 40th Street, Building 7, Suite 1, Houston, TX 77022-4104
- **www.itwinsulation.com**

IV. F. FEA MODEL OF RELIEF VALVE NOZZLE LOAD

August 26, 2010

LAR Tank Torospherical Head Under Relief Valve Loading

Bob Wands

Introduction and Summary

A relief valve weighing 350 lbs is attached to a 10 inch nozzle in the LAR tank torospherical head. The effect of this weight on the head stress and stability was examined to determine whether an independent support for the valve would be necessary.

The analysis, based on ASME Section VIII procedures, indicates that, if the torospherical head is under an external pressure of 0.2 psi, the maximum force which could be supported by the nozzle in question is 1575 lbs.

Geometry

Fig. 1 shows the vessel, head, and loaded nozzle.

The head thickness is 0.1875 inches. The nozzle thickness is 0.12 inches.

Material Properties

The torospherical head, tank, and nozzle are made of SA-240 SS304 stainless steel, with a Young's modulus at room temperature of 28.3e6 psi.

Allowable Stresses and Buckling Design Factor

The ASME Code, Section VIII, Div. 1 maximum allowable primary membrane stress for SA-240 SS304 stainless steel is 20 ksi.

From the ASME Code, Section VIII, Div. 2, Part 5, the required buckling design factor for a linear elastic buckling analysis of a spherical shell is 16.2.

Finite Element Model

The finite element model is shown in Fig. 2. It consists of approximately 15000 4-node shell elements, with a total of approximately 15000 nodes. Because the several nozzles in the head are widely separated, only the nozzle in question, and the large central penetration, were included in the model.

Two load cases were run:

1. Linear buckling - this analysis procedure requires two runs. The first is a prestress run at some arbitrary value of the applied loads. The second is the linear buckling run itself. This run uses the prestressed condition of the first run, and outputs a "load multiplier." This is the factor applied to all the loads of the preceding prestress analysis to produce buckling. For this analysis, a pressure equal to 16.2 times the actual external pressure was applied in the prestress run, and the force on the nozzle increased slowly until the buckling run produced a load factor of 1.

2. Stress - for this load case, the loads were put in at their operational loads of 0.2 psi external pressure, and 350 lbs of nozzle force. The resulting maximum stress at the nozzle was then compared to the allowable stress of 20 ksi for primary membrane stress, and the maximum nozzle load inferred by scaling.

Results

The lowest buckling mode shape for the head and nozzle is shown in Fig. 3.

The maximum force required to produce a load multiplier of 1 when the pressure has already been multiplied by the buckling design factor of 16.2 is 25530 lbs. If the pressure and load are both divided by the buckling design factor, the maximum allowable external pressure becomes the design external pressure of 0.2 psi, and the maximum allowable force on the nozzle becomes 1575 lbs.

The stresses in the region of the nozzle are shown in Fig. 4. The maximum stress is 2860 psi. Classifying this stress as primary membrane, with an allowable value of 20 ksi, is very conservative; the stress is more properly classified as primary local membrane plus bending, with an allowable value of 30 ksi. Scaling the 350 lbs relief valve weight by the factor 20000/2860 gives a maximum allowable relief valve weight of 2400 lbs.

The maximum allowable nozzle load is governed by buckling, and is 1575 lbs. The 350 lb actual weight is a factor of 4.5 lower than this.

It can be concluded that the the nozzle and head can safely support the relief valve.

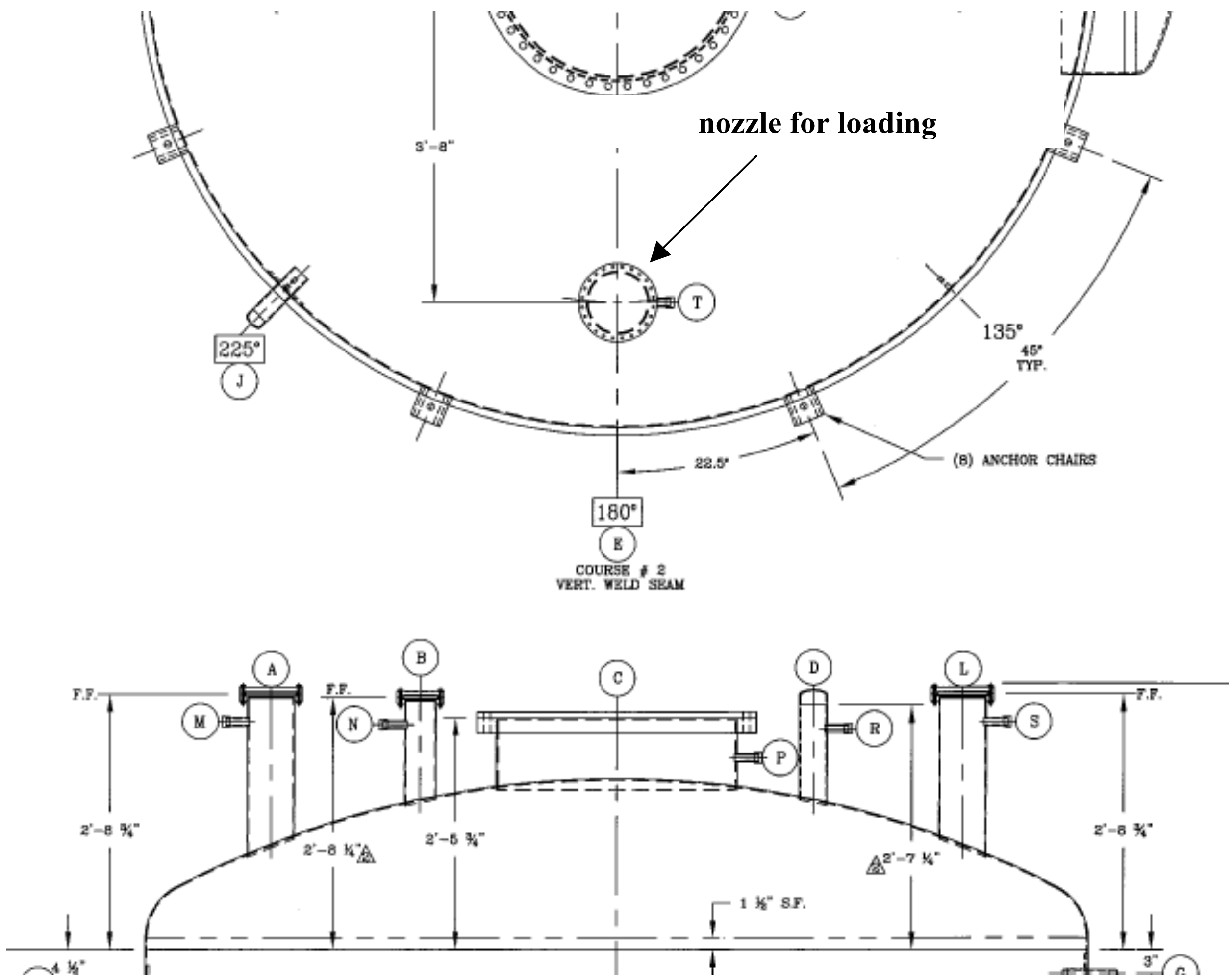
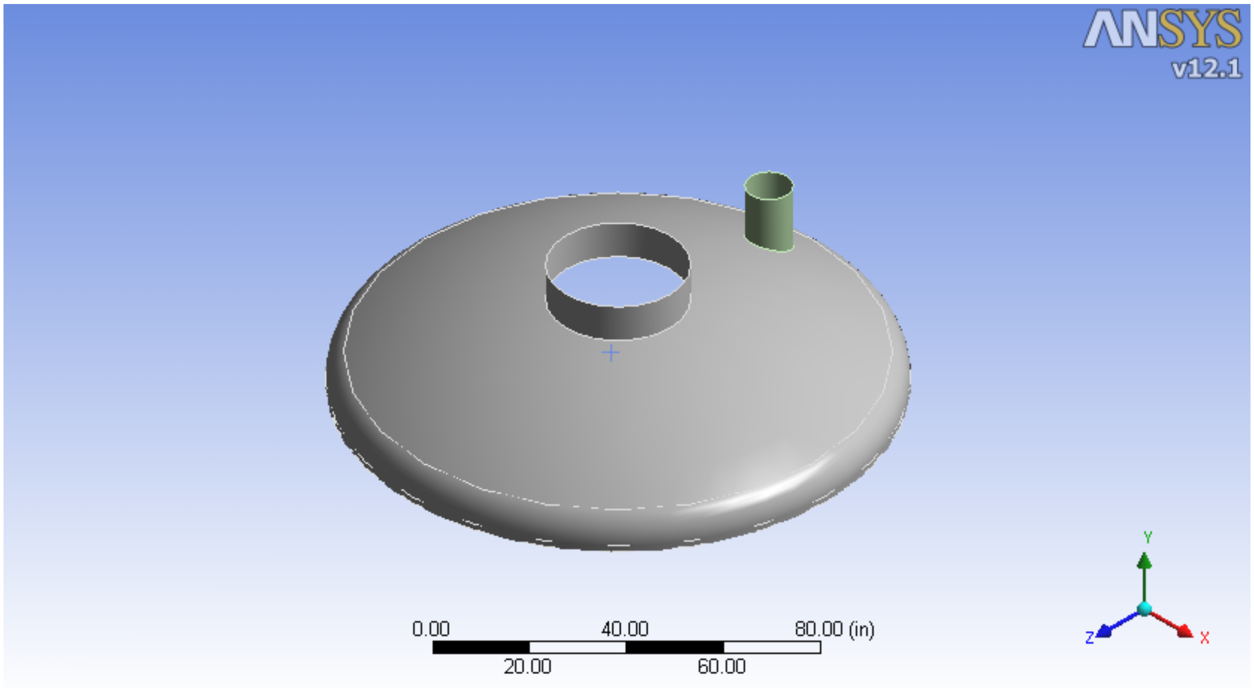


Figure 1. Tank Head and Nozzle Geometry



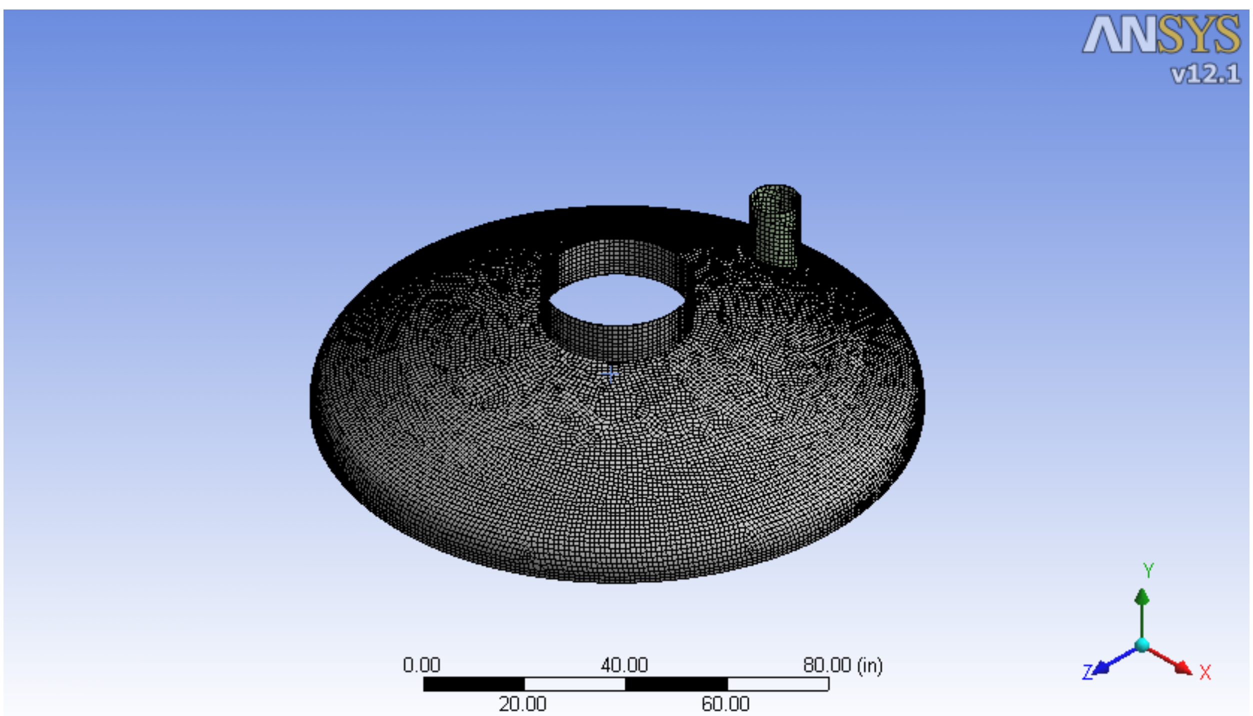


Figure 2. Solid Model (top) and Finite Element Mesh

Figure 3. Mode Shape of Model when Buckled by Nozzle Load

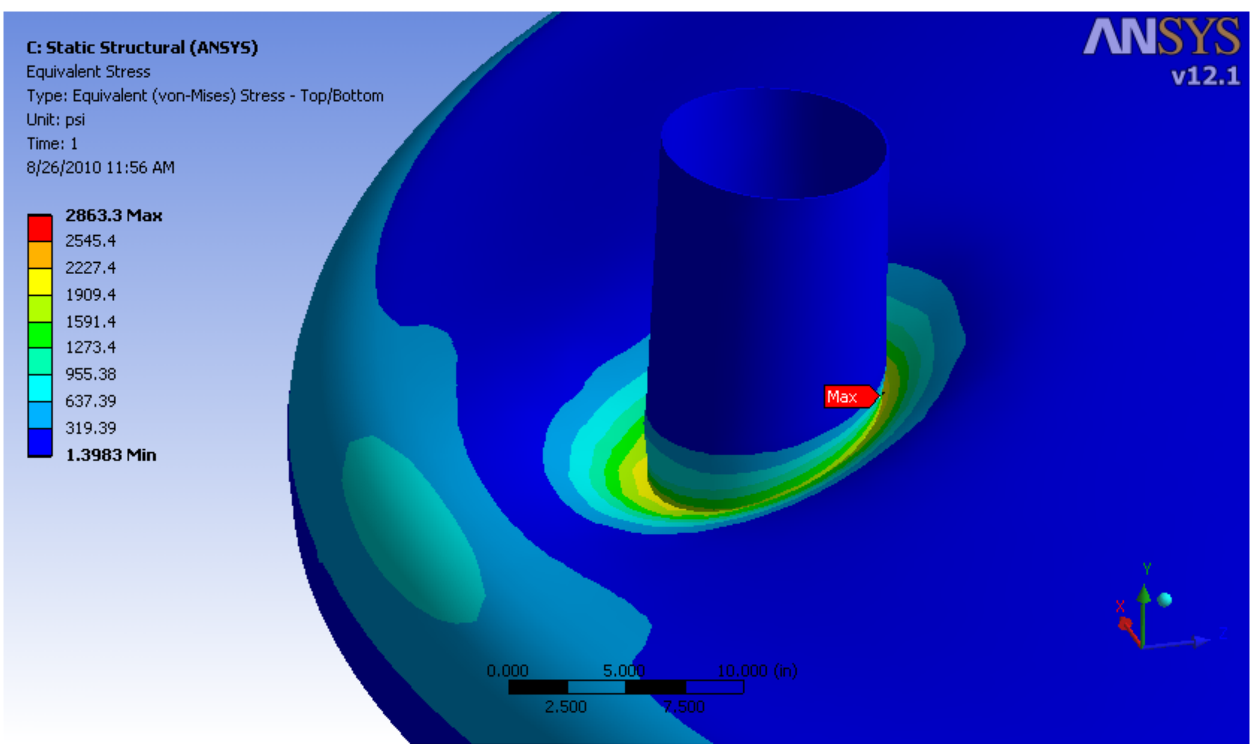
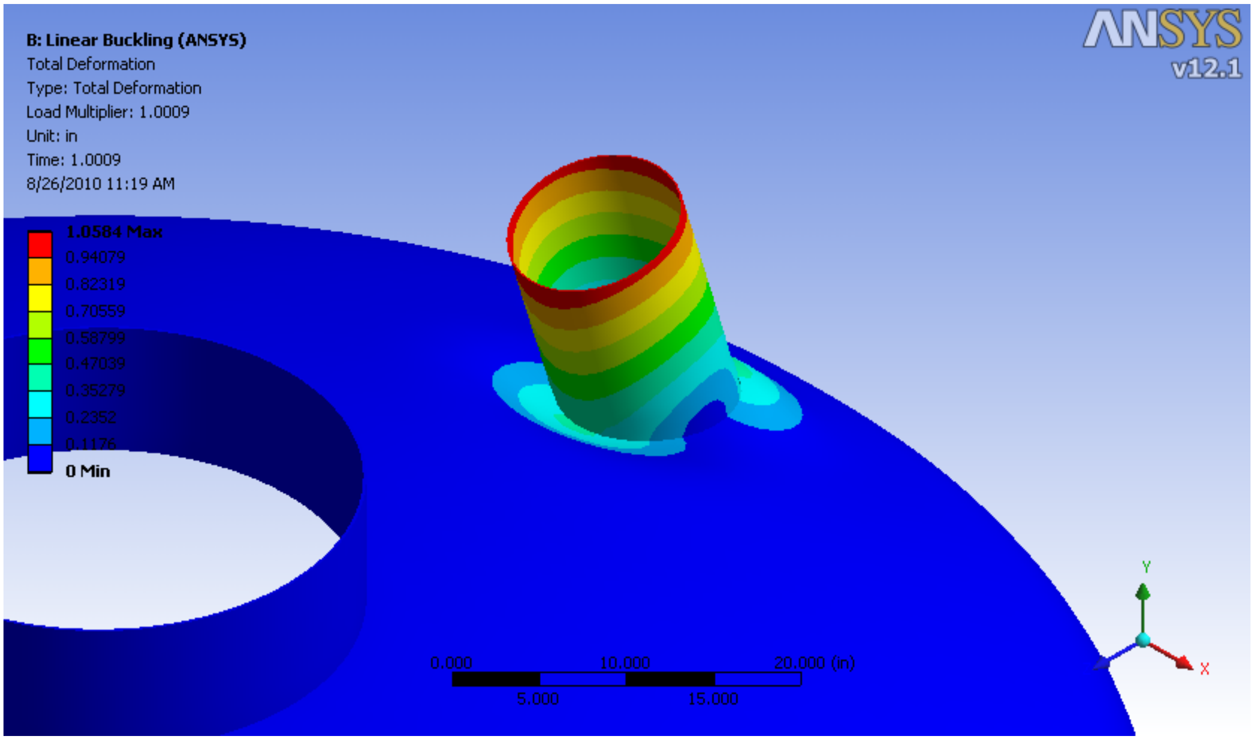


Figure 4. Stress at Nozzle under Operational Loads



B: Linear Buckling (ANSYS)
Total Deformation
Type: Total Deformation
Load Multiplier: 1.0009
Unit: in
Time: 1.0009
8/26/2010 11:19 AM
1.0584 Max
0.94079
0.82319
0.70559
0.58799
0.47039
0.35279
0.2352
0.1176
0 Min
ANSYS
v12.1
0.000
10.000
20.000 (in)
5.000
15.000
Y
X

IV. G. FEA MODEL OF EMPTY TANK EXTERNAL PRESSURE TEST

May 9, 2011

The External Pressure Rating of the LAr Tank

Bob Wands

Introduction and Summary

A commercially manufactured liquid argon vessel was delivered with calculations from the vendor based on API procedures. These calculations have been found to contain errors. The 0.2 psi external pressure rating for the vessel has been called into question.

The purpose of this analysis is to apply ASME Div. 1 design procedures to the vessel to determine its external MAWP. In addition, a 3-d FEA is performed from which an ASME Div. 2, Part 5 analysis of the primary and secondary stresses can be performed.

It is shown that the Div. 1 calculations justify an external MAWP of 0.23 psi, determined by the thickness of the circular bottom head. The Div. 2 calculations would allow this pressure to reach 0.33 psi, based on the primary membrane plus bending stress in the head near the hold-down brackets.

All other components have substantially larger external pressure ratings.

Geometry

A solid model was provided based on the vessel drawings. According to the drawings, the minimum thickness of all shells and heads is 7 gauge, which is 3/16 in, or 0.1875 in. This thickness is consistent with that used in the solid model, but may not be as large as the thickness in the actual vessel. No credit is taken for any thickness above 0.1875 inches.

Material Properties and Allowable Stress

Vessel drawings state that the material is SA-240 304 stainless steel. From the ASME Code, Section II, Part D, Table 1a, the minimum specified yield and ultimate stresses for this material are 30 ksi and 70 ksi, respectively. When used in a Div. 1 vessel, Table 1a specifies a maximum allowable stress (when operated at 100 F or below) of 20 ksi.

However, the maximum allowable stress applied in this analysis is limited to 18750 psi, based on the API standard.

Sizing of Components for External Pressure

The primary vessel components are the flanged and dished torospherical head, cylindrical shell, and flat circular bottom plate. The external pressure ratings for each of these components can be determined by Div. 1 calculations.

External MAWP of Torospherical Head

The external MAWP of the torospherical head can be determined by the procedures of Div. 1, UG-33, "Formed Heads, Pressure on Convex Side." The procedure has three steps. First, a factor "A" is established, based on the geometry of the head.

$$A = 0.125/(R_o/t)$$

where R_o = outside radius of crown portion of head = 120 in
t = thickness of head = 0.1875 in

Substituting gives A = 0.000195

Next, this factor allows entry into the charts of Section II, Part D for the specific material, from which a factor B is found. From Fig. HA-1 (the chart for austenitic steel, 18Cr-8Ni, Type 304), B = 2750.

As the last step, the factor B is used to determine the MAWP from

$$P_a = B/(R_o/t)$$

Substituting gives P_a = 4 psi.

Therefore, the MAWP of the torospherical head is 4 psi based on Div. 1 requirements.

External MAWP of Cylindrical Shell

The external MAWP of the cylindrical shell can be determined by the procedures of Div. 1, UG-28, "Thickness of Shells and Tubes Under External Pressure." This procedure is similar to that used for the torospherical head.

First, a factor A is established. This is done by calculating the ratios L/D, and D/t, where

L = length of shell = 120 in
D = outside diameter of shell = 120 in
t = thickness of shell = 0.1875 in

Therefore, L/D = 1, and D/t = 640. Entering Fig. G of Part II with these values gives A = 0.00008.

Next, the factor B is determined by entering Fig. HA-1 with the calculated value of A. This gives B = 1167.

Finally, the factor B is used to determine the MAWP from

$$P_a = 4B/3(D_o/t)$$

Substituting gives $P_a = 2.4$ psi.

External MAWP of Flat Circular Bottom Plate

The flat circular bottom plate does not collapse in the same sense that a curve shell collapses. The calculations for MAWP are stress-based, as opposed to stability-based, and typically apply to pressure on either side of the head. However, the design of the tank bolts its bottom circumference to a stiff foundation under the plate, essentially forcing the edge and center of the plate to remain in the same plane under internal pressure, and making it impossible for the plate to deflect significantly.

For external pressure, with substantial liquid in the vessel, the plate is also inhibited from deflecting inward, since doing so would require displacing the fluid upward. However, in practice, the tank could experience an external pressure with no liquid inventory present. Therefore, the head must be sized for this case.

The procedures of UG-34, "Unstayed Flat Heads and Covers," are applied. These procedures require a factor "C" which is determined by the method of attachment of the head to the shell.

The weld detail at this joint is taken from Drawing YO8-125-1 and reproduced below.

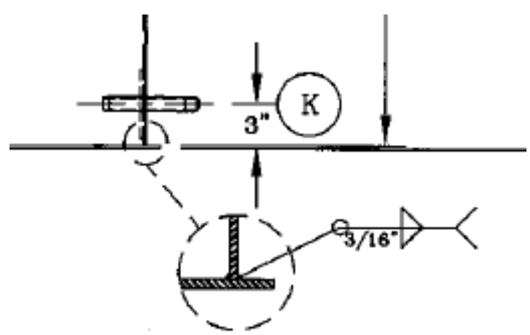


Figure 1. Weld between LAr tank cylindrical shell and flat head

The weld of Fig. 1 is shown explicitly in the Code as UG-34(f) (see Fig. 2). For a weld of this type, the text of UG-34(d) reads "C = 0.33m but not less than 0.20 for circular plates, welded to the inside of a vessel, and otherwise meeting the requirements for the respective types of welded vessels." Therefore, since the bottom plate is circular, a C = 0.2 is justified.

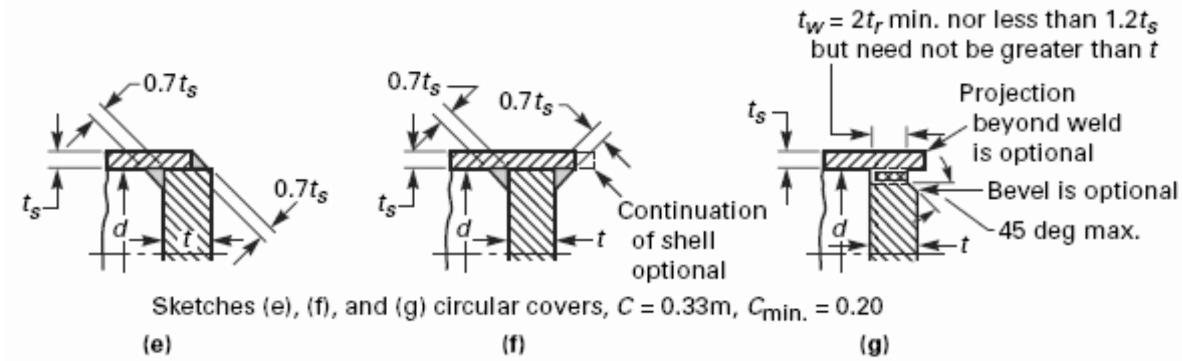


Figure 2. Weld details from Fig. UG-34. Fig. UG-34(f) is identical to LAr vessel weld

From UG-34(C)(2), the minimum required thickness of an unstayed flat head is found from

t = d*sqrt(CP/SE)

where P = pressure = 0.2 psi
C = factor = 0.2
S = maximum allowable stress = 18750 psi
E = efficiency of welds in head = 1 (no welds in head)

Substituting gives t = 0.175 inches. This is slightly less than the available 0.1875 in. actual thickness.

Adjusting the pressure until t = 0.1875 gives P = 0.23 psi.

Therefore, if the actual bottom plate thickness is 0.1875 in, then the external MAWP of the bottom head, by Div. 1 rules, is 0.23 psi.

External MAWP under Div. 2, Part 5 Rules

A finite element half-model of the vessel was created to calculate the stresses necessary to evaluate the MAWP of the bottom plate. This model, and its constraints, are shown in Fig. 3.

The analysis was run two ways: First, as a small-displacement problem in which the deflection of the bottom plate was determined entirely by its bending stiffness, and second, as a large-displacement problem in which the deflection was also affected by the diaphragm (membrane) stresses in the bottom plate. The large displacement analysis represents the most realistic simulation of the vessel bottom plate region under external loads.

The results for displacement of the bottom plate for both analyses are shown in Figs. 4 and 5. The small displacement analysis, which cannot consider the in-plane diaphragm stresses, has a maximum displacement of 2.3 in. The large displacement analysis has a maximum displacement of only 0.67 in.

The results for von Mises stress are shown in Fig. 6 and 7. The stress is significantly lower for the large displacement solution.

Although the large displacement analysis most closely simulates actual behavior, the Div. 2, Part 5 rules can be applied to the small displacement analysis only. This is primarily because stress and load are not linearly related in the large displacement analysis, and pressures which would cause the stresses to reach their limits could also involve buckling modes of the cylindrical shell, which the stress limits do not address.

To apply Div. 2, Part 5 rules, stress classification lines (SCLs) must be defined through the relevant sections in the structure. The stresses along these lines are linearized to produce membrane and bending components. The linearized stresses are compared to the allowables for the appropriate stress category.

Three SCLs were established in the bottom plate/cylindrical shell region. These are shown in Fig. 8. The first (A-B) is through the thickness at the center of the plate, and represents a region of primary membrane and bending stresses. The second (C-D) is in the cylindrical shell just above the weld at the shell/plate junction, and represents a region of primary local membrane and secondary stress. The third (E-F) is through the bottom plate in the region of a hold down bracket, and represents a region of primary membrane and bending stresses.

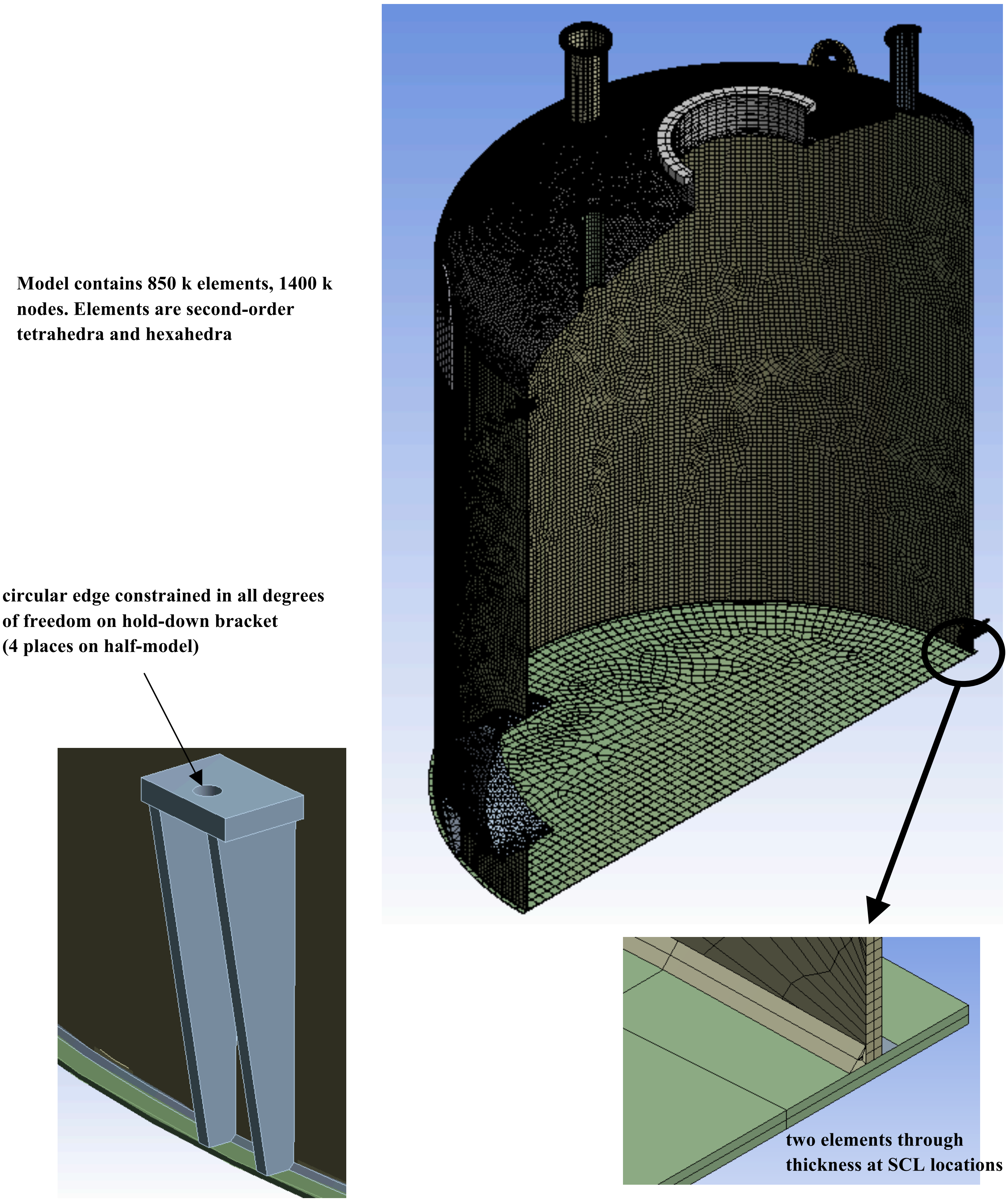


Figure 3. The FE model used for Div. 2, Part 5 Calculations

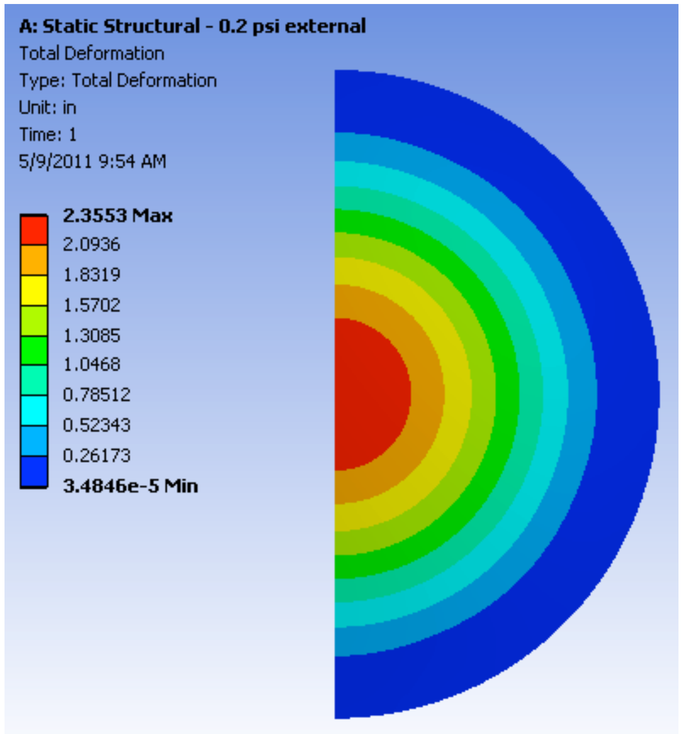


Figure 4. Deflections of Bottom Plate – small deflection analysis

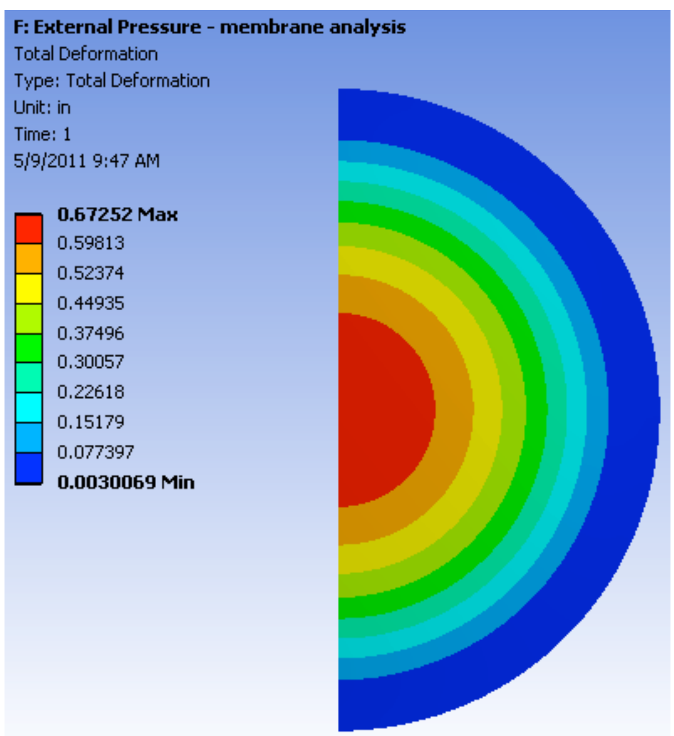


Figure 5. Deflections of Bottom Plate – large deflection analysis

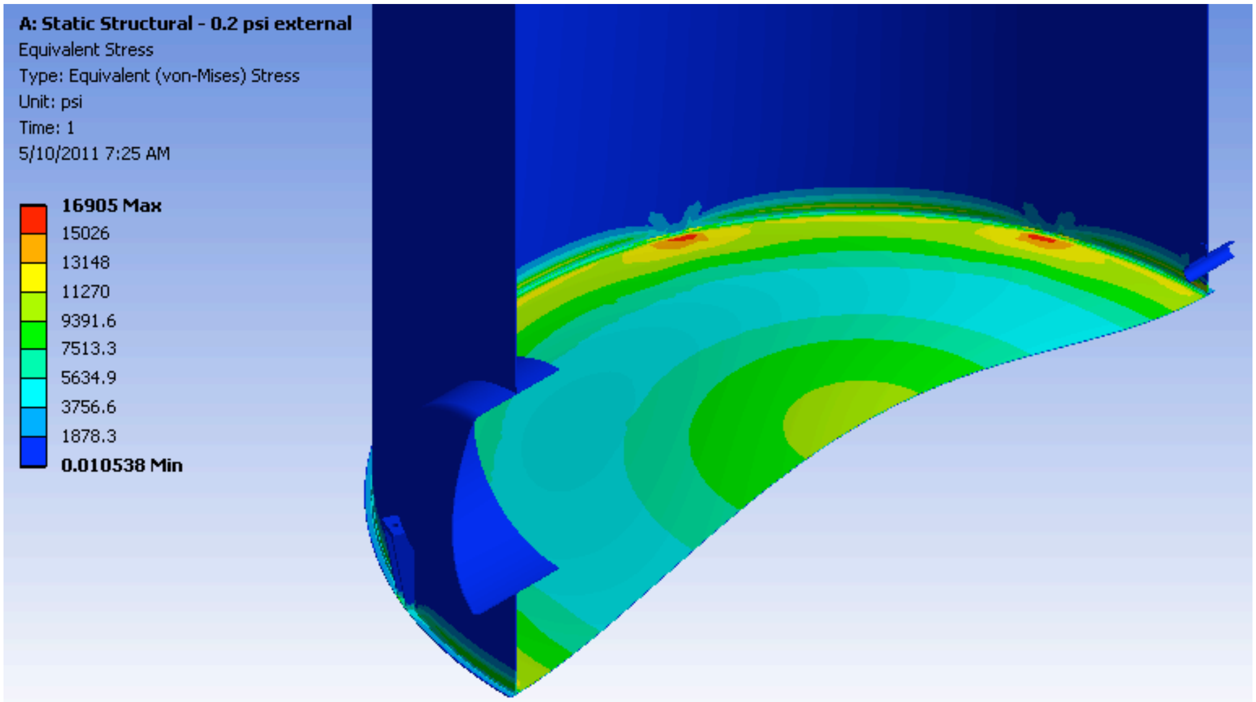


Figure 6. Stress – small displacement analysis

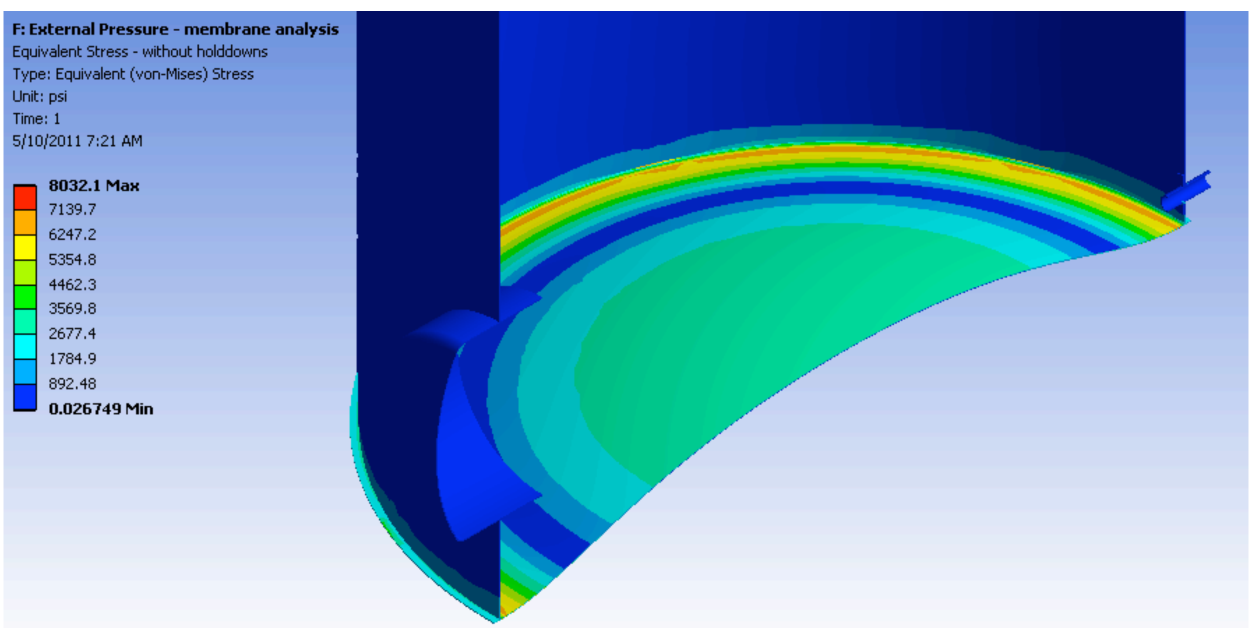
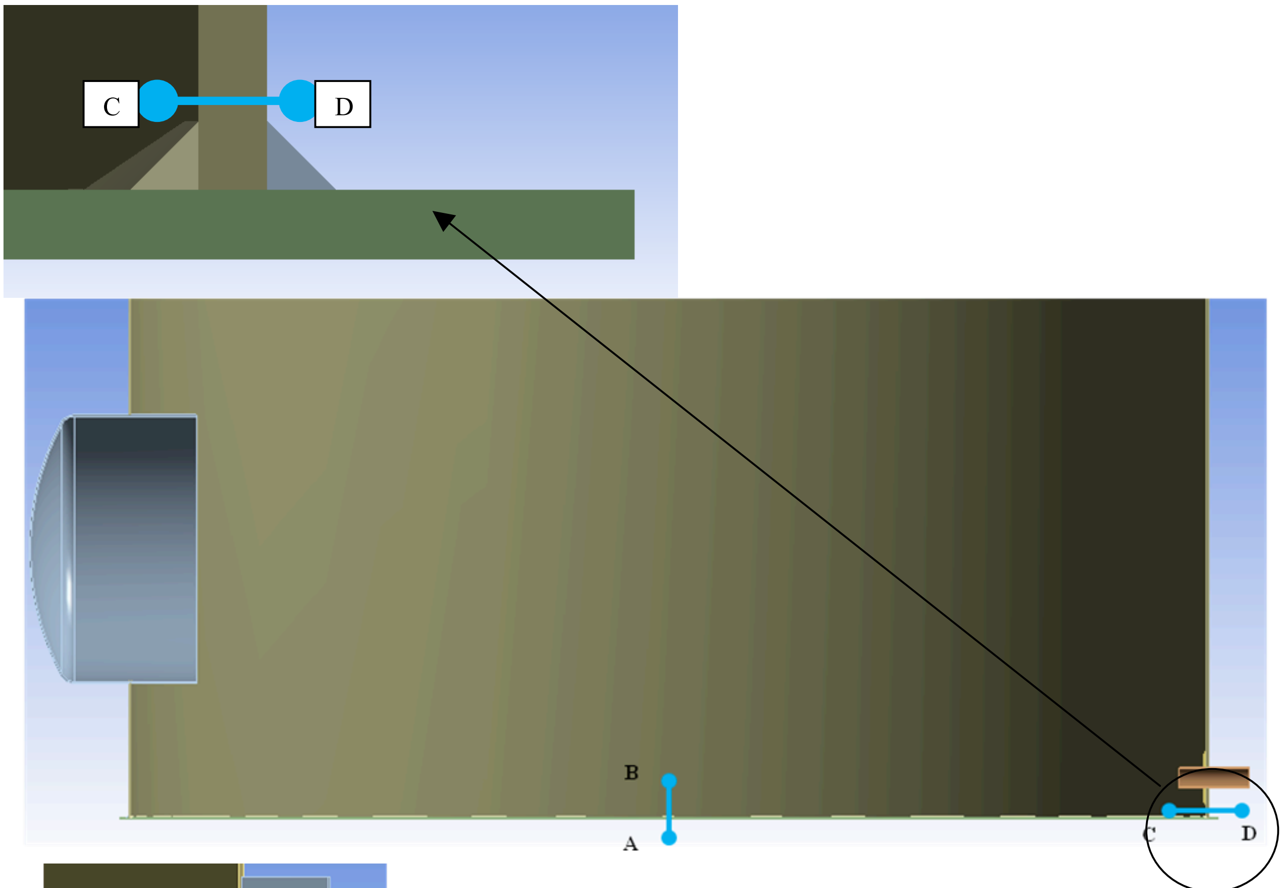
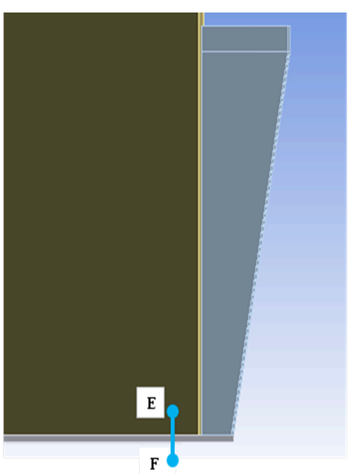


Figure 7. Stress – large displacement analysis





- **SCL 1 (A-B) is through center of bottom plate**
- **SCL2 (C-D) is through cylindrical shell just above weld**
- **SCL3 (E-F) is through bottom plate at most highly stressed section near hold down bracket**

Figure 8. Stress classification lines (SCLs) in bottom plate/shell

The allowable stresses for the membrane and combined membrane and bending stresses from the SCLs are detailed in Div. 2, Part 5, 5.2.2.2 – 5.2.2.4. Specifically, if S_a = 18750 psi, then

- Primary membrane stress is limited to S_a
- Primary membrane plus primary bending is limited to $1.5S_a$.
- Primary local membrane stress is limited to $1.5S_a$.
- Primary local membrane plus secondary bending is limited to $3S_a$.

Table I summarizes stresses across the SCLs for the small deflection analysis, as well as the allowable stresses, and the inferred MAWP.

Table I. Results for ASME Section VIII, Div. 2, Part 5 Stress analysis of bottom plate/cylindrical shell

Model	SCL	Membrane stress – psi	Bending + bending stress – psi	Stress classification	Membrane allowable stress - psi	Membrane + bending allowable stress	MAWP - psi
small deflections	A-B	150	10229	primary membrane plus bending	18750	28125	0.55
	C-D	422	10588	primary local membrane + secondary bending	28125	56250	1.05
	E-F	1622	16950	primary membrane plus bending	18750	28125	0.33

Table II summarizes the external pressure ratings of all components under Div 1 rules. The external pressure rating of the bottom plate per Div. 2, Part 5 rules is also included.

Table II. Summary of External Pressure Ratings of LAr Tank Components per ASME Code

Component	External MAWP - psi
torospherical head	4
cylindrical shell	2.4
bottom plate (Div. 1)	0.23
bottom plate (Div. 2)	0.33

Conclusions

The tank shell and heads were evaluated according to the rules of the ASME Code, Section VIII,, and it was found that the external MAWP of the LAr tank is limited by the thickness of the bottom plate, and is 0.23 psi (per Div.1) or 0.33 psi (per Div. 2).

The most conservative conclusion is that the external pressure on the tank should be limited in operation to 0.23 psi. Testing pressure can be raised to the appropriate level (0.23 x 1.25 = 0.28 psi for a pneumatic pressure test) without concern.

V. Relief Valve Sizing

Relief Valve Sizing for the LAPD Tank

Several scenarios are considered for both internal and external tank pressurization. At the end of this section the cases are summarized in a table and compared to the main tank relief valve capacities.

Fire case

The LAPD tank is located in PC4. PC4 was originally an experimental hall but is now a storage area. The floor of the enclosure is concrete and the walls are bare metal such that the building itself does not contribute significant combustible material in the vicinity of the cryogenic tank. Items in storage do include combustible materials such as wooden crates, cardboard, and signal cables. There is no hydrocarbon storage in PC4. A fire engulfing the entire LAPD cryogenic tank is not credible.

Fermilab Sr. Fire Strategist & Researcher Jim Priest flame tested the three key LAPD tank insulating materials. Jim tested an assembly of the mastic vapor barrier, the foam, and the fiberglass. The insulation was tested with several flame intensities and exposure times starting with 10 sec on and 15 sec off and then up to 1 minute plus flame exposures. The materials did not burn in the presence of the >1700 ^{o}F propane flame except for the mastic vapor barrier. The mastic vapor barrier burned when exposed to intense flame and then self extinguished within 20 seconds when the flame was removed. Video of the flame testing is available here:

http://lartpc-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=514

If material such as a wooden storage crate near the tank burns, the tank insulation will stay intact and limit the heat input.

API 2000 (sixth edition), Venting Atmospheric and Low-Pressure Storage Tanks was chosen as the standard for sizing the LAPD relief valve for fire. The scope of API 2000 includes above ground and underground refrigerated storage tanks designed for operation at pressures from vacuum through 15 psig (The LAPD tank MAWP is 3 psig). API 620, the standard used to fabricate the tank, suggests using API 2000 for relief valve sizing. Both CGA S-1.3 and API 520 state that their scope is for MAWPs exceeding 15 psig. API 2000 is very similar to API 520.

The heat input due to fire in the API standards is based upon actual tests of a tank in a pool of gasoline. The gasoline was continuously replenished and the tests were done on calm days or with wind barriers to get the highest heat load. This heat input would only be possible in a refinery or a facility with large amounts of flammable fluids present. Although this type of severe fire is not possible in PC4, the following analysis shows that the LAPD tank relief valve is adequate for the heat input of a refinery type fire if insulation credit is taken.

Engineering judgment suggests that it is reasonable to take the insulation credit based upon the following. The previously mentioned testing shows that the insulation survives exposure to a 1700 ^{o}F flame. In addition, the Fermilab Fire Department will be summoned in the event of smoke. Their typical response time is on the order of a few minutes. Each shift of firefighters will be walked thru prior to filling the tank with liquid argon to familiarize them with the area and to train them not to damage the tank insulation with high pressure water.

API 2000 section 5.2.1.4 addresses the fire condition for refrigerated tanks. Section 5.2.1.4 suggests using section 4.3.3 which contains the requirements for emergency venting capacity of non-refrigerated tanks subject to fire exposure.

Section 4.3.3 offers the following equation for the required venting capacity, q, expressed in units of standard cubic feet per hour of air:

$q = 3.091 \frac{QF}{L} \left(\frac{T}{M} \right)^{0.5}$ where

Q = the heat input from fire exposure as given by Table 4, expressed in British thermal units per hour.

F = the environmental factor from Table 9 (credit may be taken for only one environmental factor).

L = the latent heat of vaporization of the stored liquid at the relieving pressure and temperature, expressed in British thermal units per pound, 72.48 Btu/lb for for argon relieving at 18 psia (14.7 psia + 1.1 x 3.0 psi = 18 psia).

T = the absolute temperature of the relieving vapor, expressed in degrees Rankine, 160.7 ^{o}R for argon relieving at 18 psia.

M = is the relative molecular mass of the vapour, 39.948 for argon.

Note to reviewer: API 2000 uses commas to denote the decimal point and a space as the thousands separator. Thus one tenth is represented as 0,1 in API 2000 and one thousand is represented as 1 000. This documentation does NOT follow that convention.

To determine the heat input from Table 4, the tank wetted surface area, A_{TWS}, is required. The LAPD tank has a diameter *D* of 10 feet and the cylindrical sides have a height *H* of 10 feet. For the fire condition its assumed that the tank bottom and sides are wetted such that the wetted surface area is

$$A_{TWS} = \left(\frac{\pi}{4} \right) \times D^2 + \pi \times D \times H = \left(\frac{\pi}{4} \right) \times 10^2 + \pi \times 10 \times 10 = 393 ft^2.$$

From Table 4 for wetted surface areas >= 200 and < 1,000 ft^2, the heat input *Q* is calculated from the following equation

$$Q = 199{,}300 \left(A_{TWS}{}^{0.566} \right).$$

Thus for the LAPD tank the fire heat input is

$$Q = 199{,}300 \left(393^{0.566} \right) = 5.86 \times 10^6 \frac{Btu}{hr}.$$

The environmental factor *F* is explained in Table 9. It is based upon the thermal conductance of the insulation and a temperature differential of 1,600 ^{o}F when using a heat input value of 21,000 Btu / (hr x ft^2). Thus if the tank has 1 inch thick insulation with a conductance of 4 BTU x in / (hr x ft^2 x ^{o}F) the *F* factor is derived in the following manner:

$$q'' = \frac{k \Delta T}{L} = 4 \frac{Btu \times in}{hr \times ft^2 \times {}^{o}F} \times \frac{1}{1\ in} \times 1600\ {}^{o}F = 6{,}400 \frac{Btu}{hr \times ft^2}$$

$$F = \frac{6{,}400 \frac{Btu}{hr \times ft^2}}{21{,}000 \frac{Btu}{hr \times ft^2}} = 0.3$$

Such that a 1 inch thick piece of hypothetical insulation reduces the heat input to three tenths of the bare tank heat input value. For clarity the *F* factor associated with a 4 inch thick piece of insulation is also computed.

$$q'' = \frac{k\Delta T}{L} = 4\frac{Btu \times in}{hr \times ft^2 \times {}^oF} \times \frac{1}{4\ in} \times 1600\ {}^oF = 1{,}600\frac{Btu}{hr \times ft^2}$$

$$F = \frac{1{,}600\frac{Btu}{hr \times ft^2}}{21{,}000\frac{Btu}{hr \times ft^2}} = 0.075.$$

The 4 inch thick piece of insulation reduces the heat input to 0.075 of the bare tank value.

The *F* factor can be computed directly from the insulation conductance *U* in the following manner

$$F = 0.075 \times U\frac{Btu \times in}{hr \times ft^2 \times {}^oF}$$

$$F = 4\frac{Btu \times in}{hr \times ft^2 \times {}^oF} \times \frac{1}{1\ in} \times 0.075 = 0.3.$$

FNAL drawing #466366 shows the tank insulation scheme. The sides of the tank are covered with 10 inches of fiberglass and 1 inch of polyurethane modified polyisocyanurate cellular plastic foam. The tank also sits on 9 inches of this foam. The following table summarizes the tank insulation.

Tank location	Insulation	Thickness inches	Thermal conductivity at 75 ^oF Btu x in / (hr x ft^2 x ^oF)	Thermal conductivity at 300 ^oF Btu x in / (hr x ft^2 x ^oF)
Side	Owens Corning 702 Fiberglass	10	0.23	0.41
Side	ITW Trymer 2000 XP	0.75	0.19	n/a
Bottom	ITW Trymer 3000 XP	9	0.19	n/a

For simplicity the three types of insulation are modeled as one type of insulation 9 inches thick with a conductivity of 0.41 Btu x in/(hr x ft^2 x ^oF) covering all wetted surfaces. In the event of a fire the thermal conductivity of the tank insulation would vary strongly as a function of temperature. Barron's Cryogenic Systems lists the apparent thermal conductivity of fiberglass as 0.168 Btu x in / (hr x ft^2 x ^oF) when used between boundary temperatures of 300 K and 90 K. Owens Corning lists the conductivity of similar fiberglass insulation as 0.54 Btu x in / (hr x ft^2 x ^oF) at 500 ^oF. Thus the 0.41 Btu x in / (hr x ft^2 x ^oF) seems like a reasonable thermal conductivity estimate to use for the fire case.

The insulation's effective conductivity is

$$U = 0.41\frac{Btu \times in}{hr \times ft^2 \times {}^oF} \times \frac{1}{9\ in.} = 0.046\frac{Btu}{hr \times ft^2 \times {}^oF}.$$

The corresponding F factor is then

$$F = 0.075 \times 0.046 \frac{Btu}{hr \times ft^2 \times {}^oF} = 0.00345.$$

The required venting capacity is found to be

$$q = 3.091 \frac{5.86 \times 10^6 \times 0.00345}{72.48} \left(\frac{160.7}{39.948} \right)^{0.5} = 1{,}729\ SCFH_{Air} = 29\ SCFM_{AIR}.$$

Liquid pump maximum flow

If operational procedures are ignored, it would be possible for the liquid pump to push liquid thru warm piping and return vapor to the tank which then must be relieved. The worst case is to assume that the maximum liquid flow that can be produced by the pump must be relieved at room temperature by the tank relief valve.

The pump maximum flow is 12.5 GPM which is an argon mass flow of

$$12.5 \frac{gal}{\min} \times \frac{1 ft^3}{7.48\ gal} \times \frac{60 \min}{1\ hr} \times \frac{87\ lb}{ft^3} = 8{,}723 \frac{lb}{hr}.$$

Equation D.37 from API 2000 section D.9 allows conversion of this argon mass flow to an equivalent air flow:

$$q_{air} = \frac{x}{M_{air}} W_{fl} \sqrt{\frac{M_{air}}{T_{air}}} \sqrt{\frac{T_i}{M}}$$

where

x = 379.46 SCF / lb x mol

M_{air} = 29

W_{fl} = 8,723 lb/hr

T_{air} = 519.67 ^{o}R

T_i = 519.67 ^{o}R

M = 39.948 for argon

$$q_{air} = \frac{379.46}{29} 8{,}723 \sqrt{\frac{29}{519.67}} \sqrt{\frac{519.67}{39.948}} = 97{,}249\ SCFH_{AIR} = 1{,}620\ SCFM_{AIR}.$$

Ambient heat leak

LarTPC docdb document 475 estimates the tank heat leak as 2,103 W (7,175 Btu/hr).

http://lartpc-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=475

Using the API 2000 relief valve sizing equation this heat input is equivalent to a free air flow of

$$q = 3.091\frac{7{,}175}{72.48}\left(\frac{160.7}{39.948}\right)^{0.5} = 614\ SCFH_{Air} = 10\ SCFM_{AIR}\ .$$

Compromised insulation

The worst case ambient heat leak scenario is to saturate the insulation with ice. This is an unlikely scenario because the condenser cannot support the development of such a heat load. The preceding linked document describing the ambient heat leak estimates the tank surface area as 501.6 ft^2. Barron's Cryogenic Heat Transfer book estimates the thermal conductivity of ice as 1.09 Btu / (hr x ft x ^oF). If we assume a 9 inch thick block of ice surrounding the tank the heat leak delivered to the liquid argon would be

$$q = \frac{kA\Delta T}{L} = 1.09\frac{Btu}{hr \times ft \times {}^oF} \times 501.6\,ft^2 \times \frac{32^oF - -303^oF}{0.75\,ft} = 244{,}212\frac{Btu}{hr}.$$

Using the API 2000 relief valve sizing equation 12 this heat input is equivalent to a free air flow of

$$q = 3.091\frac{244{,}212}{72.48}\left(\frac{160.7}{39.948}\right)^{0.5} = 20{,}889\ SCFH_{Air} = 348\ SCFM_{AIR}.$$

Tank shell heaters

The tank has 12 pairs of heaters spaced evenly around the circumference of the cylindrical shell. These heaters are on the outside of the tank and are under the insulation. Each pair has a maximum power of 50 W for a total of 600 W or 2,047 Btu/hr.

Using the API 2000 relief valve sizing equation 12 this heat input is equivalent to a free air flow of

$$q = 3.091\frac{2{,}047}{72.48}\left(\frac{160.7}{39.948}\right)^{0.5} = 175\ SCFH_{Air} = 3\ SCFM_{AIR}.$$

Condenser

The liquid nitrogen powered condenser can create a vacuum inside the LAPD tank. The following linked document estimates the condenser power as 8,440 W or 28,798 Btu/hr.

http://lartpc-docdb.fnal.gov:8080/cgi-bin/RetrieveFile?docid=477&version=2&filename=argon%20overpres%20time%20estimate.pdf

Dividing the available heat rejection by the latent heat and density of argon gas saturated at the tank MAWP results in the following volumetric rate at which argon vapor is condensed into liquid.

$$28{,}798\frac{Btu}{hr} \times \frac{lb}{72.48\ Btu} \times \frac{1\ hr}{60\ \min} \times \frac{ft^3}{0.4363\ lb} = 15.2\ \frac{ft^3}{min}.$$

This volumetric flow of cold argon gas must be replaced by a flow of cold air. Multiplying the flow rate by the density of air at the tank conditions (18 psia, 160.7 ^oR) and then dividing by the density of air at standard conditions yields the required flow of free air into the tank.

$$15.2\ \frac{ft^3}{min}\times 0.3024\frac{lb}{ft^3}\times\frac{ft^3}{0.07635lb}=60\ SCFM_{AIR}.$$

The author notes that boiling and condensation heat transfer correlations can result in considerable error even when applied correctly to real world applications. The relief valve has capacity in excess of 10 times the calculated requirement.

Liquid pump

If the liquid pump is used to empty the tank a vacuum could be created. The liquid volume discharged at the pump's maximum rate of 12.5 GPM must be replaced by ambient air at a rate of:

$$12.5\frac{gal}{\min}\times\frac{1ft^3}{7.48\ gal}=1.67\frac{ft^3}{\min}$$

As in the previous case the flow of cold argon gas is converted to a flow of air at the standard condition:

$$1.67\ \frac{ft^3}{min}\times 0.3024\frac{lb}{ft^3}\times\frac{ft^3}{0.07635lb}=7\ SCFM_{AIR}.$$

Severed Pipe

The largest liquid connection to the tank is a 2 inch SCH 10 pipe. If this pipe was severed a vacuum could be created in the tank vapor space.

From Crane Technical Paper 410 (2009 printing) equation 6-27 can be used for the discharge of fluid:

$$Q=235.6d^2\sqrt{\frac{\Delta P}{K\rho}}$$

Q = rate of flow in GPM

d = internal diameter of the pipe, 2.157 inches.

ΔP = Available pressure drop, psi. The maximum liquid height in the tank is 10 feet such that the head available is 87 lb/ft^3 x 10 ft x 1 ft^2/144 in^2 = 6.04 psi. The maximum vapor pressure in the tank is 3 psig. Thus the total pressure available at the tank bottom relative to atmosphere is 9.04 psid.

ρ = density, 87 lb/ft^3 for liquid argon.

K = resistance coefficient, unit less. From Crane 410 page A-30 K = 0.78 for an inward projecting pipe entrance and K = 1.0 for a pipe exit.

Thus the volumetric flow out of the tank due to a severed pipe that would have to be made up by air supplied thru the vacuum relief would be

$$Q = 235.6(2.157)^2 \sqrt{\frac{9.04}{(0.78+1)87}} = 265\ GPM\ = 35.4\ \frac{ft^3}{min}.$$

This cold argon vapor flow is equivalent to a free air flow of

$$35.4\ \frac{ft^3}{min} \times 0.3024 \frac{lb}{ft^3} \times \frac{ft^3}{0.07635 lb} = 140\ SCFM_{AIR}.$$

Bellows pumps

There is one bellows pump that communicates with the tank (a Senior Aerospace MB-602). Depending upon the state of valving the pump could pressurize or evacuate the tank. The pump's maximum flow is 6 SCFM at 0 psig such that 6 SCFM is used as the maximum pressurization and evacuation rate.

Vacuum pumps

Several vacuum pumps will be available for evacuation of the argon process piping. If a mistake is made, these pumps could attempt to pull vacuum on the tank. Two Anest Iwata ISP-500C oil-free scroll vacuum pumps (21.2 CFM) were purchased for this purpose along with 3 smaller Anest Iwata ISP-90C pumps (3.8 CFM). If all five pumps attempted to evacuate the tank, the required vacuum relief would need to replace up to 54 CFM of cold argon vapor which converts to a free air equivalent of

$$54\ \frac{ft^3}{min} \times 0.3024 \frac{lb}{ft^3} \times \frac{ft^3}{0.07635 lb} = 214\ SCFM_{AIR}\ .$$

Atmospheric Pressure Changes

API 2000 section 5.2.1.2 addresses atmospheric pressure changes. If the pressure in the tank is equal to the maximum operating pressure, a drop in atmospheric pressure can cause overpressure from the expansion of vapor in the enclosed vapor space, V_{AG}, and vapor evolved from the overheat of the liquid, V_{AL}. The flow rate due to vapor expansion V_{AG}, expressed in cubic meters per hour under the actual conditions of the pressure and temperature of the enclosed vapor space, can be calculated using

$$V_{AG} = \frac{V_{tk}}{p} \cdot \frac{dp_{atm}}{dt}$$ where

V_{tk} = 24.6 m^3, maximum gaseous capacity of the empty tank, based upon the manufacturers fabrication drawing which states a volume of 6,506 gallons. This is a conservative value when liquid is in the tank as the vapor space will be a small fraction of the total volume.

p = 128,932 Pa, absolute pressure corresponding to the tank MAWP (14.7 psia + 3 psig).

$\frac{dp_{atm}}{dt} =$ 2,000 Pa/hr, rate of variation of atmospheric pressure suggested by API 2000 for both rising and falling barometric pressure.

$$V_{AG} = \frac{24.6m^3}{128{,}932Pa} \times \frac{2000Pa}{hr} = 0.4\frac{m^3}{hr}.$$

The flow rate due to the de-superheating of the liquid, V_{AL}, is estimated using the methods given in 5.2.1.3 for the calculation of the fractional proportion of the liquid, X_{gas}, that vaporizes instantaneously.

$$X_{gas} = 1 - \exp\left[\frac{C_p \cdot (T_2 - T_1)}{L}\right] \text{ where}$$

$C_p =$ 1,215 J / kg-K, specific heat capacity of liquid argon saturated at the tank MAWP.

$T_2 =$ 88.940 K, boiling point of the liquid argon in the tank after the atmospheric pressure reduction. This is based on a pressure reduction of 2,000 Pa in one hour.

$T_1 =$ 89.103 K, boiling point of the liquid argon in the tank saturated at the tank MAWP prior to the atmospheric pressure drop.

$L =$ 168,742 J/kg, latent heat of vaporization of liquid argon saturated at the tank MAWP.

$$X_{gas} = 1 - \exp\left[\frac{1{,}215 \cdot (89.103 - 88.940)}{168{,}742}\right] = 0.001173.$$

The volume of gas created by the pressure reduction of 2,000 Pa in one hour is then

$$V_{AL} = X_{gas} \times density\ of\ LAr \times volume\ of\ LAr \times GAr\ specific\ volume =$$
$$0.001173 \times 1401\frac{kg}{m^3} \times 22.2\ m^3 \times 0.1543\frac{m^3}{kg} = 5.63m^3$$

The total flow rate V_A due to a reduction in atmospheric pressure is then

$$V_A = V_{AG} + V_{AL} = 0.4\frac{m^3}{hr} + 5.6\frac{m^3}{hr} = 6.0\frac{m^3}{hr}.$$

This is equivalent to a mass flow rate of

$$6.0\frac{m^3}{hr} \times 6.881\frac{kg}{m^3} = 41.3\frac{kg}{hr} = 91\frac{lb}{hr}.$$

Which then converts to a free air flow (equation D.37) of

$$q_{air} = \frac{379.46}{29} 91 \sqrt{\frac{29}{519.67}} \sqrt{\frac{519.67}{39.948}} = 1{,}014\ SCFH_{AIR} = 17\ SCFM_{AIR}\,.$$

Thus for the largest expected fall in atmospheric pressure the tank will relieve at a rate of 17 $SCFM_{air}$. For a rise in atmospheric pressure the liquid in the tank will not flash such that only the dP/dt fraction is relevant which is about 1 $SCFM_{air}$.

Warm Gas Supply

For filter regeneration, contamination injection, and bleed up of evacuated spaces both argon and nitrogen compressed gas will be available. All sources of gas will have a pressure regulator at their source. By far the regulator with the largest flow capacity is the Matheson 3201 regulating the premix regeneration gas. Ignoring all the other system restrictions, it can deliver up to 150 $SCFM_{air.}$

Tank filling

The LAPD tank must be filled following a procedure to ensure vessel safety. The LAPD liquid argon supply tanker will have its liquid pump locked out and this will be verified by a Fermilab engineer***.*** Thus the fill rate of the tank will be governed by the vapor pressure in the supply tanker and the liquid head due to the elevation change between the supply tanker and the tank. The liquid head of the supply tanker with respect to the tank will be about 28 feet. The following calculation estimates the differential pressure across the fill line that results in a flow that matches the relief valve capacity. The fill line is assumed to be single phase liquid argon flow. This is conservative because ambient heat input and flashing due to pressure reduction will introduce vapor into the liquid flow which will reduce the mass flow rate. The calculation also assumes that liquid argon is introduced into a warm and empty tank such that the tank vents room temperature argon vapor. The 1st segment of the fill line is 1 inch Type K foam insulated copper. The 2nd segment would normally involve flow thru the filter vessels and related 1 inch sch 10 stainless steel purification piping. However it is possible to flow backwards thru the pump and into the vessel thru the pump suction piping – which is a lower resistance path to the tank. For this path the resistance of the pump itself and the resistance of the 2 inch sch 10 pump suction piping is ignored – only the resistance of the inch sch 10 portion is considered.

In a following section the as installed capacity of the relief valve is calculated to be 4,377 SCFM (262,620 SCFH) of air. Equation D.37 from API 2000 section D.9 allows conversion of this air mass flow to an equivalent argon flow:

$$W_{fl} = \frac{q_{air} M_{air}}{x \sqrt{\frac{M_{air}}{T_{air}}} \sqrt{\frac{T_i}{M}}}$$

where

q_{air} = As installed relief capacity, 262,620 SCFH of air.

x = 379.46 SCF / lb x mol

M_{air} = 29

W_{fl} = mass flow of argon in lb/hr

T_{air} = 519.67 ^{o}R

T_i = 519.67 ^oR

M = 39.948 for argon

$$W_{fl} = \frac{262{,}620 \times 29}{379.46\sqrt{\frac{29}{519.67}}\sqrt{\frac{519.67}{39.948}}} = 23{,}554\,\frac{lb}{hr}.$$

Thus the as installed relief valve capacity is 23,554 lb/hr of argon.

The pressure drop in the liquid argon fill line is calculated using the methods of Crane 410. The 1 inch type K copper portion (ID = 0.995 inches) of the fill line contains 778 inches of straight length. In addition to the straight length a 36" long 1" diameter corrugated braided flex hose connects the copper to the stainless steel purification piping. Several corrugated hose vendors suggest that pressure drop in corrugated hose is roughly 3 times that of equivalent straight piping. Thus 108 inches of straight length was added to represent the flex hose for a total length of 886 inches or 73.83 ft. The one inch type K copper also contains 3 elbows and one Cryolab ES4 manual valve with a C_v of 15.2

The 1 inch sch 10 (ID = 1.097 inches) stainless steel piping from the type K copper connection to the pump discharge contains 498 inches of straight length. This includes multiplying the length of the numerous corrugated braided flexible hoses by 3 to account for the increased pressure drop in corrugated hose. The piping also contains fourteen 90 degree changes in flow direction which are a combination of elbows and tees for this path. All fourteen are represented as elbows. This is conservative for this calculation because elbows are less restrictive than flow thru the branch of a tee. The 1 inch sch 10 stainless piping also contains one Eden Cryogenics globe valve with a C_v of 18 and one Eden Cryogenics Y pattern valve with a C_v of 27.

The total resistance of the piping is represented by:

$$K_{410\_fill\_Cu} = num_{\_elbows\_fill\_Cu} \times K_{\_elbow\_fill\_Cu} + K_{\_fill\_Cu\_pipe} + K_{\_\mathrm{pipe\_exit}} + K_{\_valve\_cryolab} + K_{\_valve\_eden\_Y}$$
$$+ 2 \times K_{\_valve\_eden\_globe} + K_{410\_SS\_to\_Cu}$$

where

$num_{\_elbows\_fill\_Cu}$ = number of elbows in the type K copper, 3.

The resistance of one type K copper elbow is represented by

$$K_{\_elbow\_fill\_Cu} = 20 \times f_{T\_fill\_Cu}$$

where the turbulent fiction factor $f_{T\_fill\_Cu} = 0.02281$ for the 0.995 inch internal diameter type K tubing.

The resistance of the straight copper pipe is represented by

$$K_{\_fill\_Cu\_pipe} = f_{\_ci\_fill\_Cu} \times \frac{L_{\_fill\_Cu\_ft}}{D_{\_fill\_Cu\_ft}}$$

where the friction factor is calculated using the Colebrook equation

$$\frac{1}{\sqrt{f_{\_ci\_fill\_Cu}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7D_{\_fill\_Cu\_ft}} + \frac{2.51}{\mathrm{Re}_{\_fill\_Cu}\sqrt{f_{\_ci\_fill\_Cu}}}\right)$$

and

$$L_{\_fill\_Cu\_ft} = 73.83\,ft$$

$$D_{\_fill\_Cu\_ft} = 0.08292\,ft$$

ε is the absolute roughness, estimated as 0.00015 ft using the data on Crane 410 page A-2 for commercial steel.

The Reynolds number for the copper piping is calculated using

$$\mathrm{Re}_{\_fill\_Cu} = 6.31 \times \frac{WCAP}{d_{small\_fill\_Cu} \times \mu}$$

where

$$d_{small\_fill\_Cu} = 0.995\ inches.$$

The mass flow rate, *WCAP*, that matches the relief valve capacity is

$$WCAP = 23{,}556\frac{lb}{hr}.$$

μ = viscosity of liquid argon calculated by EES at the average pressure ($P_{average}$) between the inlet and outlet assuming saturated liquid.

The pipe exit into the tank has a resistance of

$$K_{\_\mathrm{pipe\_exit}} = 1.0$$

and the valve *Cv*'s convert to a *K* value in the following manner:

$$K_{\_valve\_cryolab} = 890.3 \times (d^4_{small\_fill\_Cu})/C^2_{v\_cryolab}$$

$$K_{\_valve\_eden\_Y} = 890.3 \times (d^4_{small\_fill\_Cu})/C^2_{v\_eden\_Y}$$

$$K_{\_valve\_eden\_Globe} = 890.3 \times (d^4_{small\_fill\_Cu})/C^2_{v\_eden\_globe}.$$

The resistance of the stainless piping, $K_{410\_fill\_SS}$, is converted to an equivalent copper tubing resistance in the following manner:

$$K_{410\_SS\_to\_Cu} = K_{410\_fill\_SS} \times \left(d_{small\_fill\_Cu}/d_{small\_fill\_ss}\right)^4.$$

The equivalent length of pipe, $L_{\_eq\_fill\_Cu\_ft}$, for the overall pressure drop calculation is computed from

$$K_{410\_fill\_Cu} = f_{\_ci\_fill\_Cu} \times \frac{L_{\_eq\_fill\_Cu\_ft}}{D_{\_fill\_Cu\_ft}}$$

which includes the resistance of the stainless steel piping.

The resistance of the 1 inch sch 10 stainless piping is computed as

$$K_{410\_fill\_SS} = num_{\_elbows\_fill\_SS} \times K_{\_elbow\_fill\_SS} + K_{\_fill\_SS\_pipe}$$

where

$num_{\_elbows\_fill\_SS}$ = number of elbows in the stainless piping, 14.

The resistance of one stainless steel butt weld elbow is represented by

$$K_{\_elbow\_fill\_SS} = 20 \times f_{T\_fill\_SS}$$

where the turbulent friction factor $f_{T\_fill\_SS} = 0.02224$ for the 1.097 inch internal diameter stainless pipe.

The resistance of the straight stainless pipe is represented by

$$K_{\_fill\_SS\_pipe} = f_{\_ci\_fill\_SS} \times \frac{L_{\_fill\_SS\_ft}}{D_{\_fill\_SS\_ft}}$$

where the friction factor is calculated using the Colebrook equation

$$\frac{1}{\sqrt{f_{\_ci\_fill\_SS}}} = -2.0 \ \log\left(\frac{\varepsilon}{3.7 D_{\_fill\_SS\_ft}} + \frac{2.51}{\mathrm{Re}_{\_fill\_SS} \sqrt{f_{\_ci\_fill\_SS}}} \right)$$

and

$$L_{\_fill\_SS\_ft} = 41.5\, ft$$

$$D_{\_fill\_SS\_ft} = 0.09142\, ft.$$

The Reynolds number for the stainless piping is calculated using

$$\mathrm{Re}_{\_fill\_SS} = 6.31 \times \frac{WCAP}{d_{small\_fill\_SS} \times \mu}$$

where

$$d_{small\_fill\_SS} = 1.097 \ inches.$$

The pressure drop that corresponds to the relief valve capacity is computed using Crane 410 equation 6-8

$$DELTAP_{\_\tan k\_fill\_line} = \frac{3.3591 \times 10^{-6} \times f_{\_ci\_fill\_Cu} \times L_{\_eq\_fill\_Cu\_ft} \times WCAP^2}{rho_{\_fill} \times d_{small\_fill\_Cu}{}^5}$$

where $rho_{\_fill}$ is the density of saturated liquid in lb/ft^3 evaluated at the average of the inlet (P_{1p}) and outlet (P_{2p}) pressures. The outlet pressure P_{2p} is taken to be the tank MAWP of 14.4 + 3 x 1.1 = 17.7 psia. The piping inlet pressure is calculated based upon the pressure differential required to create a flow equal to the relief valve capacity.

Below is a summary of the equations that were solved simultaneously in EES the program is available in the appendix.

$$K_{\_elbow\_fill\_Cu} = 20 \times f_{T\_fill\_Cu} = 20 \times 0.02281 = 0.4562$$

$$K_{\_fill\_Cu\_pipe} = f_{\_ci\_fill\_Cu} \times \frac{L_{\_fill\_Cu\_ft}}{D_{\_fill\_Cu\_ft}} = 0.02304 \times \frac{73.83}{0.08292} = 20.52$$

$$\mathrm{Re}_{\_fill\_Cu} = 6.31 \times \frac{WCAP}{d_{small\_fill\_Cu} \times \mu} = 6.31 \times \frac{23{,}556}{0.995 \times 0.1734} = 861{,}337$$

$$\frac{1}{\sqrt{f_{\_ci\_fill\_Cu}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7 D_{\_fill\_Cu\_ft}} + \frac{2.51}{\mathrm{Re}_{\_fill\_Cu}\sqrt{f_{\_ci\_fill\_Cu}}}\right) = \frac{1}{\sqrt{0.02304}} = -2.0\ \log\left(\frac{0.00015}{3.7 \times 0.08292} + \frac{2.51}{861{,}337 \cdot \sqrt{0.02304}}\right)$$

$$K_{\_valve\_cryolab} = 890.3 \times (d^4_{small\_fill\_Cu})/C^2_{v\_cryolab} = 890.3 \times 0.995^4/15.2^2 = 3.777$$

$$K_{\_valve\_eden\_Y} = 890.3 \times (d^4_{small\_fill\_Cu})/C^2_{v\_eden\_Y} = 890.3 \times 0.995^4/27^2 = 1.197$$

$$K_{\_valve\_eden\_Globe} = 890.3 \times (d^4_{small\_fill\_Cu})/C^2_{v\_eden\_globe} = 890.3 \times 0.995^4/18^2 = 2.693$$

$$K_{\_elbow\_fill\_SS} = 20 \times f_{T\_fill\_SS} = 20 \times 0.02224 = 0.4447$$

$$K_{\_fill\_SS\_pipe} = f_{\_ci\_fill\_SS} \times \frac{L_{\_fill\_SS\_ft}}{D_{\_fill\_SS\_ft}} = 0.02251 \times \frac{41.5}{0.09142} = 10.22$$

$$\frac{1}{\sqrt{f_{\_ci\_fill\_SS}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7 D_{\_fill\_SS\_ft}} + \frac{2.51}{\mathrm{Re}_{\_fill\_SS}\sqrt{f_{\_ci\_fill\_SS}}}\right) = \frac{1}{\sqrt{0.02251}} = -2.0\ \log\left(\frac{0.00015}{3.7 \times 0.09142} + \frac{2.51}{781249 \cdot \sqrt{0.02251}}\right)$$

$$\mathrm{Re}_{\_fill\_SS} = 6.31 \times \frac{WCAP}{d_{small\_fill\_SS} \times \mu} = 6.31 \times \frac{23{,}556}{1.097 \times 0.1734} = 781{,}249$$

$$K_{410\_fill\_SS} = num_{\_elbows\_fill\_SS} \times K_{\_elbow\_fill\_SS} + K_{\_fill\_SS\_pipe} = 14 \times 0.4447 + 10.22 = 16.44$$

$$K_{410\_SS\_to\_Cu} = K_{410\_fill\_SS} \times \left(d_{small\_fill\_Cu}/d_{small\_fill\_ss}\right)^4 = 16.44 \times \left(0.995/1.097\right)^4 = 11.13$$

$$K_{410\_fill\_Cu} = num_{\_elbows\_fill\_Cu} \times K_{\_elbow\_fill\_Cu} + K_{\_fill\_Cu\_pipe} + K_{\_pipe\_exit} + K_{\_valve\_cryolab} + K_{\_valve\_eden\_Y} + 2 \times K_{\_valve\_eden\_globe} + K_{410\_SS\_to\_Cu}$$

$$K_{410\_fill\_Cu} = 3 \times 0.4562 + 20.52 + 1.0 + 3.777 + 1.197 + 2 \times 2.693 + 11.13 = 44.38$$

$$L_{\_eq\_fill\_Cu\_ft} = \frac{K_{410\_fill\_Cu} \times D_{\_fill\_Cu\_ft}}{f_{\_ci\_fill\_Cu}} = \frac{44.38 \times 0.08292}{0.02304} = 159.7\,ft$$

$$DELTAP_{\_tank\_fill\_line} = \frac{3.3591 \times 10^{-6} \times f_{\_ci\_fill\_Cu} \times L_{\_eq\_fill\_Cu\_ft} \times WCAP^2}{rho_{\_fill} \times d_{small\_fill\_Cu}^{5}}$$

$$DELTAP_{\_tank\_fill\_line} = \frac{3.3591 \times 10^{-6} \times 0.02304 \times 159.7 \times 23{,}556^2}{81.4 \times 0.995^5} = 86.39\ psi$$

$P_{1P} = 104.1\ psia$

$P_{2P} = 17.7\ psia$

$P_{average} = 60.9\,psia$

$rho_{\_fill}$ and μ evaluated for saturated liquid argon at $60.9\,psia$.

Thus it takes a differential pressure of 86.4 psi to create a mass flow of argon that matches the relief valve capacity. The 28 ft elevation change provides a liquid head of 87 lb/ft^3 x 28 ft x 1 ft^2/144 in^2 = 16.92 psi. Thus the liquid argon supply tanker must maintain a vapor pressure of less than 70 psig during the fill so that the capacity of the relief valve is not exceeded.

Summary of LAPD tank relief valve cases

	Required flow
Internal pressure	**$SCFM_{AIR}$**
Fire	29
Liquid pump to vapor	1,620
Ambient heat leak	10
Compromised insulation	348
Fill of tank from a 70 psig source	*4,377*
Tank shell heaters	3
Bellows pump	6
Warm gas supply	150
Atmospheric fall	17
Relief valve capacity as installed	*4,377*
External pressure	
Condenser	60
Liquid pump	7
Bellows pump	6
Severed pipe	140
Atmospheric rise	1
Vacuum pumps (5 total)	214

Relief valve capacity as installed	*892*

The primary relief valve is an Anderson Greenwood 9399C06SSTC dual pilot operated relief valve which provides both pressure and vacuum relief. For internal pressure its capacity as installed is 4,377 $SCFM_{AIR}$ at 10% over its 3 psig set point and 892 $SCFM_{AIR}$ for the external pressure case. For vacuum it opens at 0.18 psi external pressure and the flow rating is at the 0.2 psi external pressure vessel rating.

A remote pressure sensing line communicates the tank pressure to the relief valve pilots. Thus inlet piping pressure drop will not cause the relief valve to close. Due to the nature of the pilot relief valve, back pressure buildup in the vent will not increase set pressure or cause the valve to lose lift. However both inlet piping and vent piping pressure drop reduces valve capacity by reducing the pressure drop available across the relief valve itself. Thus the installed capacity of the relief valve is calculated for both the internal pressure and external pressure cases. Air is used for the calculations because the required relief capacities are computed in SCFM of air equivalent.

Equations for pressure drop in the inlet piping, across the relief valve, and in the vent piping were solved simultaneously using the Engineering Equation Solver (EES) software to determine the as installed relief valve capacity and the program is available in the appendix.

Inlet piping pressure drop – internal pressure case

Figure 1 shows the geometry for the internal pressure relief calculation.

Crane 410 version 11/09 equation 1-27 gives the pressure drop for isothermal compressible flow. Using this equation, the pressure drop in the inlet piping leading up to the relief valve is calculated as follows:

$$w^2 = \left[\frac{144\, g A_{inlet}{}^2}{\overline{V}_{1inlet}\left(f_{ci\_inlet}\dfrac{L_{eq\_inlet}}{D_{inlet}} + 2\ln\dfrac{P_0}{P_1}\right)}\right]\left[\frac{(P_0)^2 - (P_1)^2}{P_0}\right]$$

w = mass flow of air, lb/sec, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

g = gravitational acceleration, 32.174 ft/s^2.

D_{inlet} = inlet pipe inner diameter, feet, 7.76 inches for 8 inch OD 0.120 inch wall tubing which is 0.6467 ft.

A_{inlet} = inlet pipe cross sectional area, for 8 inch OD 0.120 inch wall tubing:

$$\frac{\pi}{4}\left(7.76^2\right)\, in^2 = 47.295 in^2 = 0.3284\, ft^2.$$

P_0 = inlet pressure, psia, equal to the tank maximum pressure of 14.4 + 3 x 1.1 = 17.7 psia.

P_1 = inlet piping outlet pressure (relief valve inlet pressure), psia, calculated value.

$\overline{V}_{1inlet}$ = inlet specific volume of the fluid, 10.88 ft^3/lb for air at 60 ^{o}F and 17.7 psia.

f_{ci_inlet} = computed using the Colebrook equation which is Crane 410 equation 1-20

$$\frac{1}{\sqrt{f_{ci\_inlet}}} = -2.0 \ \log\left(\frac{\varepsilon}{3.7D_{inlet}} + \frac{2.51}{R_{e\_inlet}\sqrt{f_{ci\_inlet}}}\right)$$

where

ε = the absolute roughness, estimated as 0.00015 ft using the data on Crane 410 page A-24 for commercial steel.

R_{e_inlet} = the Reynolds number Re is computed using Crane 410 equation 6-3.

$$R_{e\_inlet} = 6.31\frac{W}{d_{inlet}\mu}$$

W = mass flow of air, lb/hr, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

d_{inlet} = inlet pipe internal diameter, 7.76 inches.

μ = absolute (dynamic) viscosity of air, 0.018035 centipoise at 60 ^oF.

L_{eq_inlet} = Equivalent length of pipe in ft, calculated using the methods of Crane 410 – see below calculations.

The path to the relief valve has 4.32 feet, L_{inlet}, of straight pipe. In addition to the resistance of the straight pipe, the inward projecting entrance has a resistance value of K = 0.78. Thus the total resistance between the vessel and the relief valve is computed as

$$K_{410inlet} = 0.78 + f_{ci\_inlet}\frac{L_{inlet}}{D_{inlet}} = 0.78 + 0.01513\frac{4.32\,ft}{\frac{7.76\ in}{12\frac{in}{ft}}} = 0.881.$$

The equivalent length of straight pipe is then calculated as follows:

$$L_{eq\_inlet} = \frac{K_{410inlet}D_{inlet}}{f_{ci\_inlet}} = \frac{0.881 \times \frac{7.76\ in}{12\frac{in}{ft}}}{0.01513} = 37.73\,ft$$

$$R_{e\_inlet} = 6.31\frac{W}{d_{inlet}\mu} = 6.31\frac{20{,}051}{7.76 \times 0.018035} = 904{,}022$$

$$\frac{1}{\sqrt{f_{ci\_inlet}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7D_{inlet}} + \frac{2.51}{R_{e\_inlet}\sqrt{f_{ci\_inlet}}}\right) = \frac{1}{\sqrt{0.0151}} = -2.0\ \log\left(\frac{0.00015}{3.7\times 0.6467} + \frac{2.51}{904{,}022\sqrt{0.0151}}\right)$$

$$w^2 = \left[\frac{144\,gA_{inlet}^{\ 2}}{\overline{V}_{1inlet}\left(f_{ci\_inlet}\dfrac{L_{eq\_inlet}}{D_{inlet}} + 2\ln\dfrac{P_0}{P_1}\right)}\right]\left[\frac{(P_0)^2 - (P_1)^2}{P_0}\right] =$$

$$5.57^2 = \left[\frac{144\times 32.17\times 0.3284^2}{10.88\left(0.0151\dfrac{37.73}{0.6467} + 2\ln\dfrac{17.7}{17.388}\right)}\right]\left[\frac{(17.7)^2 - (17.388)^2}{17.7}\right].$$

Thus the inlet piping pressure drop is 0.312 psi.

Relief valve pressure drop – internal pressure case

The Anderson Greenwood Low Pressure POPRV Catalog gives the relationship between the relief valve orifice area and the volumetric flow rate as

$$\mathrm{V} = \frac{4645K_d P_1 FA}{\sqrt{MTZ}}.$$

The subsonic flow factor, *F*, based on the ratio of specific heats and pressure drop across the valve is defined as

$$F = \sqrt{\frac{k}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]}.$$

The subsonic valve coefficient, K_d is define as

$$K_d = 0.650\left(\frac{P_2}{P_1}\right)^{-0.349}.$$

V = Gas flow capacity expressed in $SCFM_{air}$ at 14.7 psia and 60 ^{o}F.

A = Relief valve orifice area, 28.89 in^2, for a 6 inch 9300 series pilot relief valve.

M = Molecular weight of the flowing gas, 29 for air.

T = Absolute relieving temperature, 519.67 Rankine.

Z = Compressibility factor, Z = 1.

P_1 = Relief valve inlet pressure, psia, equal to the inlet piping outlet pressure.

P_2 = Relief valve outlet pressure, psia, equal to the vent piping inlet pressure.

k = Ratio of the specific heats of gas, 1.4 for air.

$$K_d = 0.650\left(\frac{P_2}{P_1}\right)^{-0.349} = 0.650\left(\frac{15.085}{17.388}\right)^{-0.349} = 0.683$$

$$F = \sqrt{\frac{k}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]} = \sqrt{\frac{1.4}{1.4-1}\left[\left(\frac{15.085}{17.388}\right)^{\frac{2}{1.4}} - \left(\frac{15.085}{17.388}\right)^{\frac{1.4+1}{1.4}}\right]} = 0.3371$$

$$\mathrm{V} = \frac{4645 K_d P_1 F A}{\sqrt{MTZ}} = \frac{4645 \times 0.683 \times 17.388 \times 0.3371 \times 28.89}{\sqrt{29 \times 519.67 \times 1}} = 4{,}377\,SCFM_{Air}$$

Thus the pressure drop across the relief valve is 2.303 psi.

The specific volume of air at 14.7 psia and 60 ^{o}F is 13.0968 ft^3/lb. Thus, as a check, the air flow converts to the mass flow w of

$$\frac{4{,}377\,ft^3}{\min} \times \frac{lb}{13.0968\,ft^3} \times \frac{1\min}{60\sec} = 5.57\frac{lb}{\sec}.$$

Vent piping pressure drop– internal pressure case

Again utilizing the equation for isothermal compressible flow, the pressure drop in the vent piping leading up to the relief valve is calculated as follows:

$$w^2 = \left[\frac{144\, g A_{vent}{}^2}{\overline{V}_{1vent}\left(f_{ci\_vent}\dfrac{L_{eq\_vent}}{D_{vent}} + 2\ln\dfrac{P_{1p}}{P_{2p}}\right)}\right]\left[\frac{\left(P_{1p}\right)^2 - \left(P_{2p}\right)^2}{P_{1p}}\right]$$

w = mass flow of air, lb/sec, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

g = gravitational acceleration, 32.174 ft/s^2.

D_{vent} = vent pipe inner diameter, feet, 8.329 inches for 8 inch SCH 10 pipe which is 0.6941 ft.

A_{vent} = vent pipe cross sectional area, for 8 inch SCH 10 pipe:

$$\frac{\pi}{4}\left(8.329^2\right)\ in^2 = 54.4848\ in^2 = 0.3784\,ft^2.$$

P_{1p} = vent inlet pressure, psia, equal to the calculated relief valve outlet pressure (P_2) of 15.085 psia.

P_{2p} = vent outlet pressure, psia, equal to an atmospheric pressure of 14.4 psia.

$\overline{V}_{1vent}$ = vent inlet fluid specific volume, 12.76 ft^3/lb for air at 60 ^oF and 15.085 psia.

f_{ci_vent} = computed using the Colebrook equation

$$\frac{1}{\sqrt{f_{ci\_vent}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7D_{vent}} + \frac{2.51}{R_{e\_vent}\sqrt{f_{ci\_vent}}}\right)$$

where

ε = the absolute roughness, estimated as 0.00015 ft using the data on Crane 410 page A-24 for commercial steel.

R_{e_vent} = the Reynolds number R_e is computed using Crane 410 equation 6-3.

$$R_{e\_vent} = 6.31\frac{W}{d_{vent}\mu}$$

W = mass flow of air, lb/hr, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

d_{vent} = vent pipe internal diameter, 8.329 inches.

μ = absolute (dynamic) viscosity of air, 0.018035 centipoise at 60 ^oF.

L_{eq_vent} = Equivalent length of pipe in ft, calculated using the methods of Crane 410 – see below calculations.

The path from the relief valve to atmosphere has 8 feet, L_{vent}, of straight pipe. In addition to the resistance of the straight pipe there are five elbows. Each elbow is an 8 inch SCH 10 long radius elbow which has a r/d of 1.44. Thus the K value for one bend is 14 x f_T from page A-30 of Crane 410. f_T is the friction factor in the zone of complete turbulence which is equal to 0.01396 for clean commercial steel pipe with an inside diameter of 8.329 inches according to the plot on page A-26 of Crane 410. In addition to the resistance of the straight pipe and elbows, the pipe exit has a resistance value of K = 1.0. Thus the total resistance between the vessel and the relief valve is computed as

$$K_{410vent} = f_{ci\_vent}\frac{L_{vent}}{D_{vent}} + 5\times 14 f_{T\_vent} + 1.0 = 0.0150\frac{8\,ft}{\frac{8.329\ in}{12\frac{in}{ft}}} + 5\times 14\times 0.01396 + 1.0 = 2.15.$$

The equivalent length of straight pipe is then calculated as follows:

$$L_{eq\_vent} = \frac{K_{410vent} D_{vent}}{f_{ci\_vent}} = \frac{2.15 \times \dfrac{8.329\ in}{12\dfrac{in}{ft}}}{0.015} = 99.49\ ft$$

$$R_{e\_vent} = 6.31 \frac{W}{d_{vent}\mu} = 6.31 \frac{20{,}051}{8.329 \times 0.018035} = 842{,}280$$

$$\frac{1}{\sqrt{f_{ci\_vent}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7 D_{vent}} + \frac{2.51}{R_{e\_vent}\sqrt{f_{ci\_vent}}}\right) = \frac{1}{\sqrt{0.015}} = -2.0\ \log\left(\frac{0.00015}{3.7 \times 0.6941} + \frac{2.51}{842{,}280\sqrt{0.015}}\right)$$

$$w^2 = \left[\frac{144 g A_{vent}^{\ 2}}{\overline{V}_{1vent}\left(f_{ci\_vent}\dfrac{L_{eq\_vent}}{D_{vent}} + 2\ln\dfrac{P_{1p}}{P_{2p}}\right)}\right]\left[\frac{\left(P_{1p}\right)^2 - \left(P_{2p}\right)^2}{P_{1p}}\right] =$$

$$5.57^2 = \left[\frac{144 \times 32.17 \times 0.3784^2}{12.76\left(0.015\dfrac{99.48}{0.6941} + 2\ln\dfrac{15.085}{14.400}\right)}\right]\left[\frac{(15.085)^2 - (14.4)^2}{15.085}\right].$$

Thus the vent pressure drop is 0.685 psi.

The installed internal pressure relief capacity of the relief valve is 4,377 SCFM$_{air}$.

The as installed relief valve capacity for the vacuum case is calculated in the same manner except that the flow is reversed.

Vent piping pressure drop – external pressure case

Figure 2 shows the geometry for the internal pressure relief calculation.

For the external pressure case, the vent piping becomes the inlet piping. Utilizing the equation for isothermal compressible flow, the pressure drop in the vent piping leading up to the relief valve is calculated as follows:

$$w^2 = \left[\frac{144 g A_{vent}^{\ 2}}{\overline{V}_{1vent}\left(f_{ci\_vent}\dfrac{L_{eq\_vent}}{D_{vent}} + 2\ln\dfrac{P_{1p}}{P_{2p}}\right)}\right]\left[\frac{\left(P_{1p}\right)^2 - \left(P_{2p}\right)^2}{P_{1p}}\right]$$

w = mass flow of air, lb/sec, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

g = gravitational acceleration, 32.174 ft/s^2.

D_{vent} = vent pipe inner diameter, feet, 8.329 inches for 8 inch SCH 10 pipe which is 0.6941 ft.

A_{vent} = vent pipe cross sectional area, for 8 inch SCH 10 pipe:

$$\frac{\pi}{4}\left(8.329^2\right)\ in^2 = 54.4848\ in^2 = 0.3784\,ft^2.$$

P_{1p} = vent outlet pressure, psia, equal to the calculated relief valve inlet pressure (P_2) of 14.374 psia.

P_{2p} = vent inlet pressure, psia, equal to an atmospheric pressure of 14.40 psia.

$\overline{V}_{1vent}$ = vent inlet fluid specific volume, 13.37 ft^3/lb for air at 60 ^{o}F and 14.40 psia.

f_{ci_vent} = computed using the Colebrook equation

$$\frac{1}{\sqrt{f_{ci\_vent}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7D_{vent}} + \frac{2.51}{R_{e\_vent}\sqrt{f_{ci\_vent}}}\right)$$

where

ε = the absolute roughness, estimated as 0.00015 ft using the data on Crane 410 page A-24 for commercial steel.

R_{e_vent} = the Reynolds number R_e is computed using Crane 410 equation 6-3.

$$R_{e\_vent} = 6.31\frac{W}{d_{vent}\mu}$$

W = mass flow of air, lb/hr, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

d_{vent} = vent pipe internal diameter, 8.329 inches.

μ = absolute (dynamic) viscosity of air, 0.018035 centipoise at 60 ^{o}F.

L_{eq_vent} = Equivalent length of pipe in ft, calculated using the methods of Crane 410 – see below calculations.

The path from atmosphere to the relief valve inlet has 8 feet, L_{vent}, of straight pipe. In addition to the resistance of the straight pipe there are five elbows. Each elbow is an 8 inch SCH 10 long radius elbow which has a r/d of 1.44. Thus the K value for one bend is 14 x f_T from page A-30 of Crane 410. f_T is the friction factor in the zone of complete turbulence which is equal to 0.01396 for clean commercial steel pipe with an inside diameter of 8.329 inches according to the plot on page A-26 of Crane 410. In addition to the resistance of the straight pipe and elbows, the pipe entrance has a resistance value of K = 0.78. Thus the total resistance between the vessel and the relief valve is computed as

$$K_{410vent} = f_{ci\_vent}\frac{L_{vent}}{D_{vent}} + 5\times 14 f_{T\_vent} + 0.78 = 0.0176\frac{8\,ft}{\frac{8.329\ in}{12\frac{in}{ft}}} + 5\times 14\times 0.01396 + 0.78 = 1.96.$$

The equivalent length of straight pipe is then calculated as follows:

$$L_{eq\_vent} = \frac{K_{410vent}D_{vent}}{f_{ci\_vent}} = \frac{1.96\times\frac{8.329\ in}{12\frac{in}{ft}}}{0.01756} = 77.44\ ft$$

$$R_{e\_vent} = 6.31\frac{W}{d_{vent}\mu} = 6.31\frac{4{,}087}{8.329\times 0.018035} = 171{,}659$$

$$\frac{1}{\sqrt{f_{ci\_vent}}} = -2.0\ \log\left(\frac{\varepsilon}{3.7D_{vent}} + \frac{2.51}{R_{e\_vent}\sqrt{f_{ci\_vent}}}\right) = \frac{1}{\sqrt{0.01756}} = -2.0\ \log\left(\frac{0.00015}{3.7\times 0.6941} + \frac{2.51}{171{,}659\sqrt{0.01756}}\right)$$

$$w^2 = \left[\frac{144gA_{vent}{}^2}{\overline{V}_{1vent}\left(f_{ci\_vent}\frac{L_{eq\_vent}}{D_{vent}} + 2\ln\frac{P_{2p}}{P_{1p}}\right)}\right]\left[\frac{\left(P_{2p}\right)^2 - \left(P_{1p}\right)^2}{P_{2p}}\right] =$$

$$1.135^2 = \left[\frac{144\times 32.17\times 0.3784^2}{13.37\left(0.01756\frac{77.44}{0.6941} + 2\ln\frac{14.400}{13.374}\right)}\right]\left[\frac{(14.400)^2 - (14.374)^2}{14.400}\right].$$

Thus the vent pressure drop is 0.02552 psi for the external pressure case where the vent acts as the inlet piping to the relief valve.

Relief valve pressure drop – external pressure case

The Anderson Greenwood Low Pressure POPRV Catalog gives the relationship between the relief valve orifice area and the volumetric flow rate as

$$\mathrm{V} = \frac{4645K_dP_1FA}{\sqrt{MTZ}}.$$

The subsonic flow factor, F, based on the ratio of specific heats and pressure drop across the valve is defined as

$$F = \sqrt{\frac{k}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]}.$$

For vacuum relief the subsonic valve coefficient K_d is defined as

$$K_d = 0.55.$$

V = Gas flow capacity expressed in $SCFM_{air}$ at 14.7 psia and 60 ^oF.

A = Relief valve orifice area, 28.89 in^2, for a 6 inch 9300 series pilot relief valve.

M = Molecular weight of the flowing gas, 29 for air.

T = Absolute relieving temperature, 519.67 Rankine.

Z = Compressibility factor, Z = 1.

P_1 = Relief valve outlet pressure for vacuum relief, psia, equal to the inlet piping outlet pressure.

P_2 = Relief valve inlet pressure for vacuum relief, psia, equal to the vent piping outlet pressure.

k = Ratio of the specific heats of gas, 1.4 for air.

$$F = \sqrt{\frac{k}{k-1}\left[\left(\frac{P_1}{P_2}\right)^{\frac{2}{k}} - \left(\frac{P_1}{P_2}\right)^{\frac{k+1}{k}}\right]} = \sqrt{\frac{1.4}{1.4-1}\left[\left(\frac{14.22}{14.374}\right)^{\frac{2}{1.4}} - \left(\frac{14.22}{14.374}\right)^{\frac{1.4+1}{1.4}}\right]} = 0.1032$$

$$\mathrm{V} = \frac{4645 K_d P_2 F A}{\sqrt{MTZ}} = \frac{4645 \times 0.55 \times 14.374 \times 0.1032 \times 28.89}{\sqrt{29 \times 519.67 \times 1}} = 892\ SCFM_{Air}$$

Thus the pressure drop across the relief valve is 0.1549 psi.

The specific volume of air at 14.7 psia and 60 ^oF is 13.0968 ft^3/lb. Thus, as a check, the air flow converts to the mass flow *w* of

$$\frac{892\, ft^3}{\min} \times \frac{lb}{13.0968\, ft^3} \times \frac{1\min}{60\sec} = 1.135\frac{lb}{\sec}.$$

Inlet piping pressure drop – external pressure case

Using isothermal compressible equation, the pressure drop in the inlet piping leading up to the relief valve is calculated as follows:

$$w^2 = \left[\frac{144 g A_{inlet}{}^2}{\overline{V}_{1inlet} \left(f_{ci\_inlet} \frac{L_{eq\_inlet}}{D_{inlet}} + 2 \ln \frac{P_1}{P_0} \right)} \right] \left[\frac{(P_1)^2 - (P_0)^2}{P_1} \right]$$

w = mass flow of air, lb/sec, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

g = gravitational acceleration, 32.174 ft/s^2.

D_{inlet} = inlet pipe inner diameter, feet, 7.76 inches for 8 inch OD 0.120 inch wall tubing which is 0.6467 ft.

A_{inlet} = inlet pipe cross sectional area, for 8 inch OD 0.120 inch wall tubing:

$$\frac{\pi}{4}\left(7.76^2\right) in^2 = 47.295 in^2 = 0.3284 ft^2.$$

P_0 = inlet piping outlet pressure, psia, equal to the tank maximum pressure below ambient of 14.4 – 0.2 = 14.2 psia.

P_1 = inlet piping inlet pressure (relief valve outlet pressure during vacuum relief), psia, calculated value.

$\overline{V}_{1inlet}$ = inlet specific volume of the fluid, 13.54 ft^3/lb for air at 60 ^{o}F and 14.22 psia.

f_{ci_inlet} = computed using the Colebrook equation which is Crane 410 equation 1-20

$$\frac{1}{\sqrt{f_{ci\_inlet}}} = -2.0 \log\left(\frac{\varepsilon}{3.7 D_{inlet}} + \frac{2.51}{R_{e\_inlet}\sqrt{f_{ci\_inlet}}} \right)$$

where

ε = the absolute roughness, estimated as 0.00015 ft using the data on Crane 410 page A-24 for commercial steel.

R_{e_inlet} = the Reynolds number Re is computed using Crane 410 equation 6-3.

$$R_{e\_inlet} = 6.31 \frac{W}{d_{inlet}\mu}$$

W = mass flow of air, lb/hr, calculated based upon the available pressure drop and the resistance of the inlet piping, the vent piping, and the relief valve itself.

d_{inlet} = inlet pipe internal diameter, 7.76 inches.

μ = absolute (dynamic) viscosity of air, 0.018035 centipoise at 60 ^{o}F.

L_{eq_inlet} = Equivalent length of pipe in ft, calculated using the methods of Crane 410 – see below calculations.

The path from relief valve and back into the tank has 4.32 feet, L_{inlet}, of straight pipe. In addition to the resistance of the straight pipe, during vacuum relief a pipe exit resistance of k = 1.0 applies. Thus the total resistance between the vessel and the relief valve is computed as

$$K_{410inlet} = 1.0 + f_{ci\_inlet}\frac{L_{inlet}}{D_{inlet}} = 1.0 + 0.01749\frac{4.32\,ft}{\frac{7.76\;in}{12\frac{in}{ft}}} = 1.117$$

The equivalent length of straight pipe is then calculated as follows:

$$L_{eq\_inlet} = \frac{K_{410inlet}D_{inlet}}{f_{ci\_inlet}} = \frac{1.117\times\frac{7.76\;in}{12\frac{in}{ft}}}{0.01749} = 41.3\,ft$$

$$R_{e\_inlet} = 6.31\frac{W}{d_{inlet}\mu} = 6.31\frac{4{,}087}{7.76\times 0.018035} = 184{,}246$$

$$\frac{1}{\sqrt{f_{ci\_inlet}}} = -2.0\;\log\left(\frac{\varepsilon}{3.7D_{inlet}} + \frac{2.51}{R_{e\_inlet}\sqrt{f_{ci\_inlet}}}\right) = \frac{1}{\sqrt{0.01749}} = -2.0\;\log\left(\frac{0.00015}{3.7\times 0.6467} + \frac{2.51}{184{,}264\sqrt{0.01749}}\right)$$

$$w^2 = \left[\frac{144\,gA_{inlet}^{\;2}}{\overline{V}_{1inlet}\left(f_{ci\_inlet}\frac{L_{eq\_inlet}}{D_{inlet}} + 2\ln\frac{P_1}{P_0}\right)}\right]\left[\frac{(P_1)^2 - (P_0)^2}{P_1}\right] =$$

$$1.135^2 = \left[\frac{144\times 32.17\times 0.3284^2}{13.54\left(0.0151\frac{41.3}{0.6467} + 2\ln\frac{14.220}{14.200}\right)}\right]\left[\frac{(14.220)^2 - (14.200)^2}{14.22}\right].$$

Thus the inlet piping pressure drop is 0.01956 psi.

The installed vacuum relief capacity of the relief valve is 892 SCFM$_{air}$.

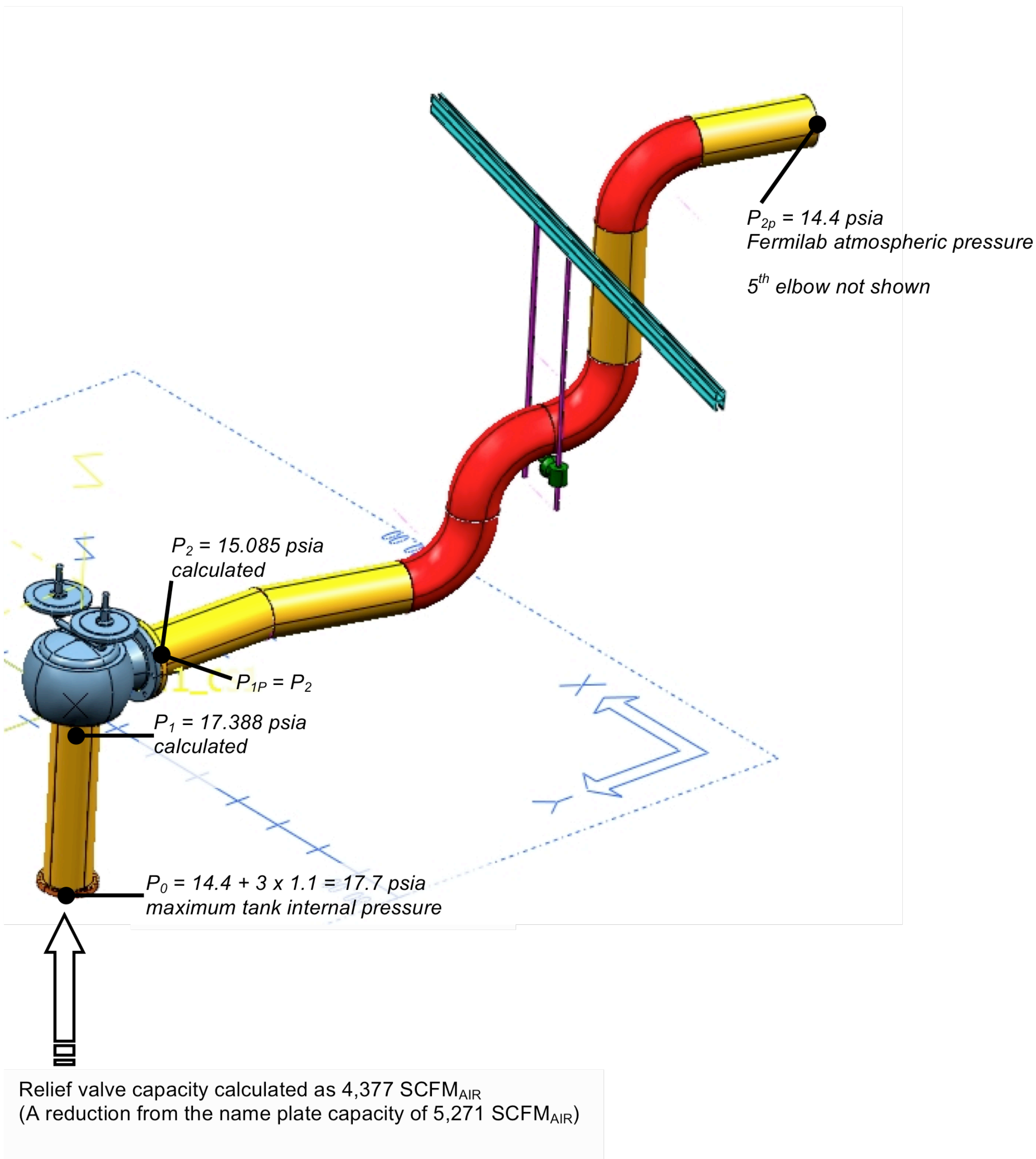


Figure 1: Relief valve parameters for determining internal pressure capacity as installed.

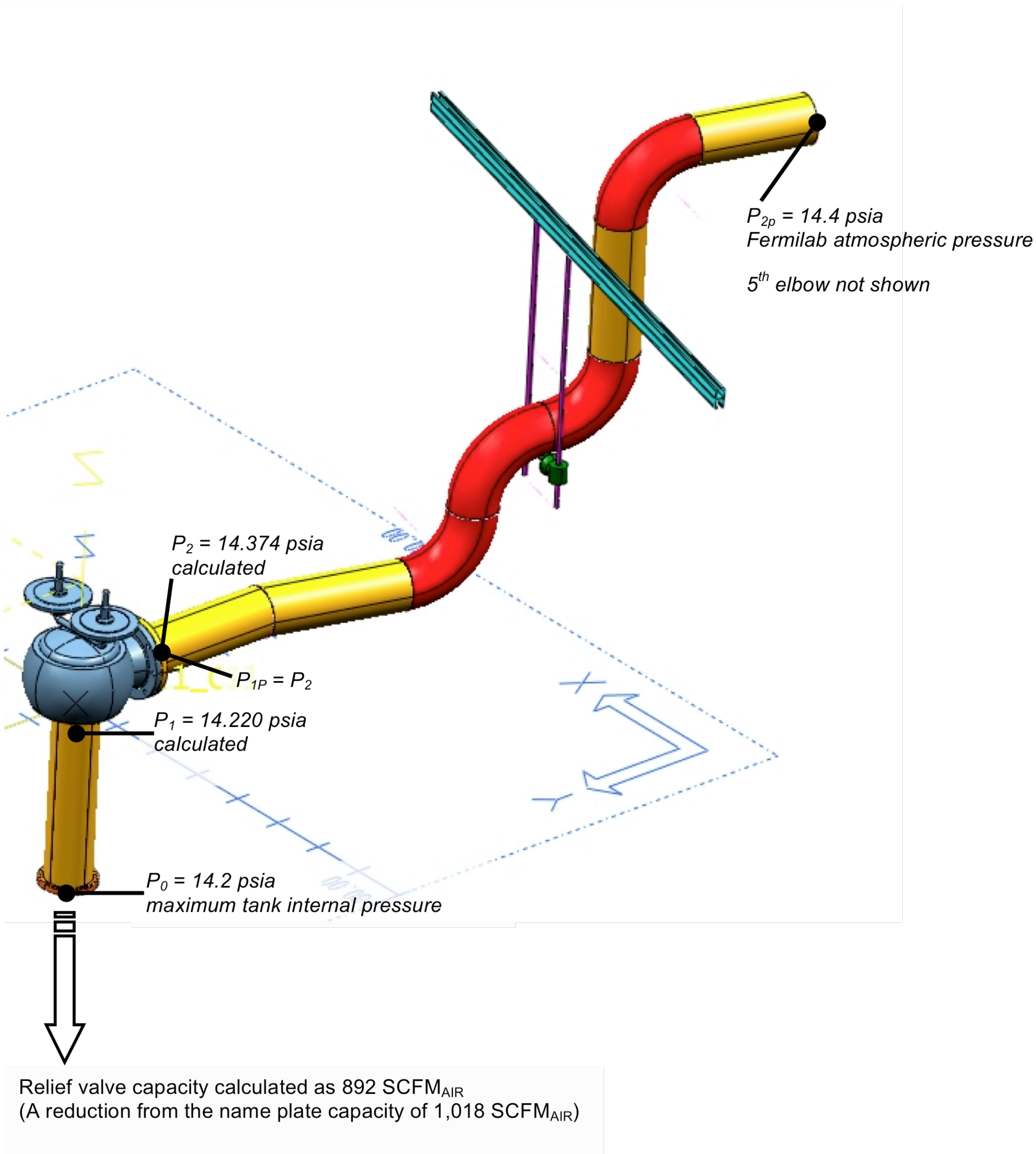


Figure 2: Relief valve parameters for determining external pressure capacity as installed.

Over filling of the tank

The tank is rated for an internal pressure of 3 psig in the vapor space while full of liquid argon. Thus the pressure at the base of the tank under 10 ft. of liquid head could be as high as 3 psi + 10 ft x 87 lb / ft^3 x 1 ft^2 / 144 in^2 = 9 psi. The liquid head pressure in the tank is solely determined by the height of liquid in the tank. If the tank was overfilled and liquid argon filled a vent pipe to an elevation above the tank, the tank pressure rating could then be exceeded. This scenario is independent of the supply tanker elevation. A tank level supply trailer using vapor pressure to push liquid into the LAPD tank could overfill the tank and create a build up of liquid argon in a vent line at an elevation higher than the tank.

The liquid argon supplier will deliver a trailer of liquid argon to the site and the trailer will then be placed solely under Fermilab control. The filling of the tank will be administratively controlled by procedure to ensure the tank is not over filled.

Piping attached to the tank

The tank manufacturer provided pipe stubs welded to the tank wall along with reinforcing pads. To these pipe stubs the vacuum jacketed argon process piping was welded. Both the vacuum jacket and argon piping contain braided flexible hoses to allow for movement between the tank and piping. The vacuum jacket braided flexible hoses are restrained with threaded rods because the braided hoses shrink under external pressure and the associated pressure thrust forces for the 3” and 5” diameter vacuum jacket hoses are substantial. The threaded rods resist buckling but still allow for lateral movement. Annotated drawings of the piping attached to the tank are attached.

Acceptable nozzle loading

The pilot relief valve mounted on the LAPD tank weighs 246 pounds. Bob Wands performed a FEA analysis to determine the maximum acceptable vertical loading of this nozzle and found it to be 1,575 pounds. The analysis is attached. This is the heaviest load that will be applied to any nozzle.

Tyco Valves & Controls, LP

TVC Midwest Region
554 Territorial Drive
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(630) 343-3333 Fax (630) 343-3334

QUOTE

Date: 03/19/10	Reference: Page 1 of 1
FERMI LABS	Quoted by: Don Pratl E-mail: dpratl@tycovalves.com
	Tyco Territory Manager: Trevor Hansen e-mail: thansen@tycovalves.com
TERRY TOPE Ph: (630)840-2666/ Fax: 630-840-3694	QUOTATION #: 8103217-01

DAYS TO DELIVER ARO	VALID UNTIL	PAYMENT TERMS	SHIPPING TERMS	FREIGHT
		Net 30 Days		Bestway PPA

ITEM	QTY.	DESCRIPTION	UNIT PRICE	TOTAL
		**************************** SHIPMENT: 16 WEEKS ARO TERMS: NET 30 DAYS FREIGHT: PPA F.O.B.: STAFFORD, TX VALIDITY: 30 DAYS FROM QUOTATION DATE **************************************		
3	1	9399C06SSTC 6 X 8 AG 9399C DUAL PILOT OPERATED PRESSURE & VACUUM RELIEF VALVE BODY: 316SS INTERNALS: 316SS PILOT: 316SS DIAPHRAGM: TEFLON SOFT GOODS: TEFLON PRESSURE SET: 3 PSIG VACUUM SET: .18 PSIG CAPACITY PRESSURE: 5271 SCFM @ 60F CAPACITY VACUUM: 1018 SCFM @ 60F ACCESSORIES: NONE TAG# PRV001	17460.00	17460.00
1		Lines Total	Total Order Total	17460.00 17460.00

Tyco Valves & Controls Canada Inc.'s standard sales terms, conditions and warranty shall apply unless modified above. These terms and conditions form part of this Quote and shall supersede any inconsistent terms and conditions between Tyco Valves & Controls Canada Inc. and the Buyer.

Last Page

ALL DELIVERIES STATED ARE SUBJECT TO PRIOR SALE.

tyco *Flow Control*

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Bolingbrook, IL 60440
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Pressure Relief Valve Sizing & Selection Report

No	Prpd.	Chk.	Appr.	Date	Revision

Quote Number:

Client: *TVC, Boilingbrook*
Location:
Project: *FERMI LAB*
End-User Ref. No.:
Project Ref. No.:

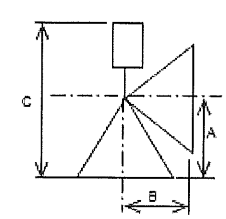
1	**VALVE ID**				
2	Tag No.	*PRV001*			
3	Service				
4	PID No.				
5	Line No.			Quantity	
6				1	
7	**GENERAL**				
8	Valve Type	*Pilot-Operated Pressure & Vacuum*			
9	Safety / Relief	*Safety*	Balanced	*Yes*	
10	Nozzle	*Full*	Bonnet	*Closed*	
11	**CONNECTIONS**				
12	Inlet	*6"*	*Flngd.*	*150#*	*RF*	Standard
13	Outlet	*8"*	*Flngd.*	*150#*	*RF*	
14	**MATERIALS OF CONSTRUCTION**				
15	**MAIN**	Body / Base	*SS SA351-CF8M*		
16	**VALVE**	Cap / Case	*SS A240-304/316 (Single)*		
17	Trim	Nozzle	*SST (LP)*	*316 SST*	
18	Seat	Soft Goods	*FEP (Film)*	*Teflon®*	
19	**PILOT VALVES**		Pressure Pilot	Vacuum Pilot	
20	Body		*SS A479-316/316L*	*SS A479-316/316L*	
21	Seat		*Teflon®*	*Teflon®*	
22	Diaphragms		*Teflon®*	*Teflon®*	
23	Soft Goods		*Teflon®*	*Teflon®*	
24	Spring		*316 SST*	*316 SST*	
25	Tubing	Fittings	*316 SST*	*316 SST CPI*	
26	Accessories	*Remote Sense Connection*			
27					
28					
29					
30	**SIZING / SELECTION SUMMARY**				
31	Valve Model No.	*9399C06SSTC*			
32	Brand	*Anderson Greenwood*			
33	**Area**	in²	Calculated	Selected Valve	
34	Pressure Case		*5.631*	*28.89*	
35	Vacuum Case		*1.169*	*28.89*	
36	**Flow**	SCFM	Required	Maximum / Valve	
37	Pressure Case		*1622*	*8321.838*	
38	Vacuum Case		*64*	*1582.074*	
39	Pressure Nameplate	*5271 SCFM, Air @ 60°F, 14.7 psia*			
40	Vacuum Nameplate	*1018 SCFM, Air @ 60°F, 14.7 psia*			

41	**SIZING DATA**				
42	Design Code	*Non-Code*	Sizing Std.	*API2000*	
43	Sizing Basis				
44	Fluid State at Inlet	*Gas / Vapor*			
45	Relieving Case	*Pressure & Vacuum Relief*			
46	***Fluid Properties***				
47	Press.	Fluid Name		*Argon*	
48		Mol. Wt., M	Comp., Z	*39.95000*	*1.00000*
49		k (Cp / Cv)	Fs	*1.67000*	*0.391*
50	Vac.	Fluid Name		*Argon*	
51		Mol. Wt., M	Comp., Z	*39.95000*	*1.00000*
52		k (Cp / Cv)	Fs	*1.67000*	*0.115*
53	***Sizing Coefficients***			Unit	-
54		K, Gas	Kd, Gas	*0.628*	*0.698*
55		Kb	Kc		
62		Vacuum K, Gas		*0.495*	
57	***Required Capacity***			Unit	SCFM
58		Pressure	Vacuum	*1622*	*64*
59	***Pressures***				
60	System	Unit	Operating		
61		MAWP	MAWV		
62		Atmospheric (Barometric)		*14.696 psia*	
63	Pressure	Unit	Set	*psig*	*3*
64		Over Pressure		*0.3*	*10%*
65		Back Pressure	Constant Superimposed		*0*
66			Variable Superimposed		*0*
67			Built-Up		*0*
68			Total		*0*
69		Inlet Loss		*0*	*0%*
70		Flowing Pressure		*17.996 psia*	
71	Vacuum	Unit	Set	*psig*	*0.18*
72		Under Pressure		*0.018*	*10%*
73		Flowing Pressure		*14.696 psia*	
74	***Temperatures***			Unit	°F
75		Operating			
76		Relieving - Pressure Case		*-303.07*	
77		Relieving - Vacuum Case		*-303.07*	
78		Design Min	Design Max		
79	Estimated Reaction Force				
80	Estimated Noise Level (db)			*71.9 at 100-ft*	

Tag Notes

Valve Dimensions

in	A	*4.32*
	B	*12*
	C	*26.7*
lb	Weight	*246*



Printed On: 11-May-2010	TYCO PRV²SIZE Software Version 2.0.3728.17257	Sheet 1 of 5

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Flow Control

Tyco Valves & Controls
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Bolingbrook, IL 60440
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dpratl@tycovalves.com

Pressure Relief Valve Calculation Report

No	Prpd.	Chk.	Appr.	Date	Revision

Quote Number:

Client: *TVC, Boilingbrook*
Location:
Project: *FERMI LAB*

End-User Ref. No.:
Project Ref. No.:

1	**VALVE ID**			4	**SIZING DATA**		
2	Tag No.	*PRV001*		5	Design Code	*Non-Code*	Sizing Std. *API2000*
3	Valve Model No.	*9399C06SSTC*	Qty. *1*	6	Fluid State at Inlet	*Gas / Vapor*	

Pressure

Inputs:

Name	Symbol	Input Value	Equation Value
k, (Cp / Cv)	k	1.67000	1.67000
Atm. Pressure	Patm	14.696 psia	14.696 psia
Set Pressure	Pset	3 psig	3 psig
Over Pressure	Pover	0.3 psig	0.3 psig
Inlet Loss	Ploss	0 psig	0 psig
Total Back Pressure	Pback	0 psig	0 psig
Relieving Pressure	P1	17.996 psia	17.996 psia
Outlet Pressure	P2	14.696 psia	14.696 psia
Transition to Full Open	Tp	0.65	0.65
Shape Factor	E	-0.349	-0.349
Molecular Weight	M	39.95000	39.95000
Relieving Temperature	T	-303.07 °F	156.600000 °R
Compressibility	Z	1.00000	1.00000
Orifice Area	A	28.89 in²	28.89 in²
Kd	Kd	0.698	0.698
Fs	Fs	0.391	0.391
Required Pressure Flow	Vreq	1622 SCFM	97320.000 SCFH
Pressure Flow Capacity	V	8321.838 SCFM	499310.29 SCFH
Press. Ratio	PR	0.817	0.817
Flow Capacity	W	52564.583 lb/hr	52564.583 lb/hr
Distance from Valve	r	100 ft	100 ft

Calculations:

Gas Constant Calculation

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

- C = 377.9

Pressures Calculation for Gas / Steam Service

$$P_1 = P_{SET} + P_{OVER} - P_{LOSS} + P_{ATM}$$
$$P_2 = P_{BACK} + P_{ATM}$$

- P1 = 17.996 psia
- P2 = 14.696 psia

Absolute Pressure Ratio

$$PR = \frac{P_2}{P_1}$$

- PR = 0.817

Theoretical Pressure Ratio

$$TPR = \left[\frac{2}{k+1}\right]^{k/(k-1)}$$

- TPR = 0.487

Subsonic Flow Factor

$$F_s = \sqrt{\frac{k}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]}$$

- Fs = 0.391

Theoretical Pressure Ratio

$$TPR = \left[\frac{2}{k+1}\right]^{k/(k-1)}$$

- TPR = 0.487

Absolute Pressure Ratio

$$PR = \frac{P_2}{P_1}$$

- PR = 0.817

Flow Coefficient for ALP Product Line

$$K_d = K_{MAX}$$
$$X = PR$$

- Kd = 0.698

Calculated Volumetric Flow for Sub-Critical Gas/Vapor

$$V = \frac{278700 K_d A P_1 F_s}{\sqrt{MTZ}}$$

- V = 499310.29 SCFH
  = 8321.838 SCFM

Required Orifice Area from Max. Volumetric Flow

$$A_{req} = \frac{A_{sel} V_{req}}{V_{sel}}$$

- Areq = 5.631 in²

Noise Level @ 100-ft for 1/PR <= 2.859

$$L_{100} = \left[87.75 \log_{10}\left(\frac{1}{PR}\right) + 14.09\right] + \left[10 \log_{10}\left(0.29354 \frac{WkT}{M}\right)\right]$$

- L100 = 71.9 db

Noise Level @ Distances Other Than 100-ft

$$L_P = L_{100} - 20 \log_{10}\left(\frac{r}{100}\right)$$

- Lp = 71.9 db

Vacuum			
Inputs:			
Name	Symbol	Input Value	Equation Value
k, (Cp / Cv)	k	1.67000	1.67000
Atm. Pressure	Patm	14.696 psia	14.696 psia
Set Vacuum	Vset	0.18 psig	0.18 psig
Under Pressure	Vover	0.018 psig	0.018 psig
Relieving Pressure	P1	14.696 psia	14.696 psia
Outlet Pressure	P2	14.498 psia	14.498 psia
Kmax	Kmax	0.55	0.55
Molecular Weight	M	39.95000	39.95000
Relieving Temperature	T	-303.07 °F	156.600000 °R
Compressibility	Z	1.00000	1.00000
Orifice Area	A	28.89 in²	28.89 in²
Kd	Kd	0.55	0.55
Fs	Fs	0.115	0.115
Required Vacuum Flow	Vreq	64 SCFM	3840.000 SCFH
Vacuum Flow Capacity	V	1582.074 SCFM	94924.435 SCFH

Calculations:

Gas Constant Calculation

$$C = 520\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

- C = 377.9

Pressures Calculation for Gas / Steam Service

$$P_1 = P_{ATM}$$

$$P_2 = P_{ATM} - V_{SET} - V_{OVER}$$

- P1 = 14.696 psia
- P2 = 14.498 psia

Absolute Pressure Ratio

$$PR = \frac{P_2}{P_1}$$

- PR = 0.987

Theoretical Pressure Ratio

$$TPR = \left[\frac{2}{k+1}\right]^{k/(k-1)}$$

- TPR = 0.487

Subsonic Flow Factor

$$F_S = \sqrt{\frac{k}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{k}} - \left(\frac{P_2}{P_1}\right)^{\frac{k+1}{k}}\right]}$$

- Fs = 0.115

Flow Coefficient for ALP Product Line

$$K_d = K_{MAX}$$

- Kd = 0.55

Calculated Volumetric Flow for Sub-Critical Gas/Vapor

$$V = \frac{278700 K_d A P_1 F_s}{\sqrt{MTZ}}$$

- V = 94924.435 SCFH
= 1582.074 SCFM

Required Orifice Area from Max. Volumetric Flow

$$A_{req} = \frac{A_{sel} V_{req}}{V_{sel}}$$

- Areq = 1.169 in²

tyco
Flow Control

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Pressure Relief Valve Dimensional Drawing

No	Prpd.	Chk.	Appr.	Date	Revision

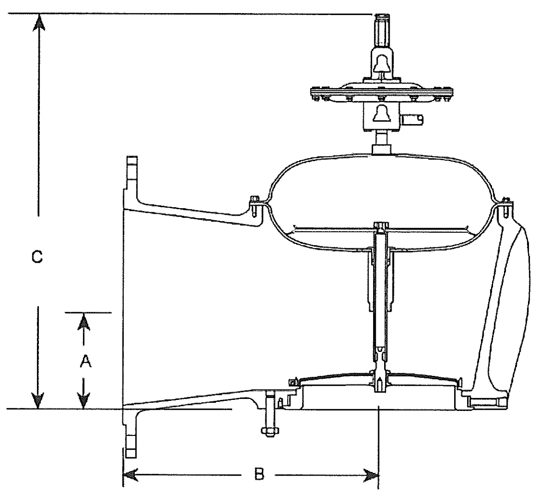
Quote Number:

Client: *TVC, Boilingbrook*
Location:
Project: *FERMI LAB*

End-User Ref. No.:
Project Ref. No.:

	VALVE ID			
1	**VALVE ID**			
2	Tag No.	*PRV001*		
3	Service			
4	PID No.			
5	Line No.		Quantity	
6			1	

7	**SELECTION SUMMARY**					
8	Valve Model No.	*9399C06SSTC*				
9	Brand	*Anderson Greenwood*				
10	**CONNECTIONS**					
11	Inlet	*6"*	*Flngd.*	*150#*	*RF*	Standard
12	Outlet	*8"*	*Flngd.*	*150#*	*RF*	



Wt. =	*246 lb*	=	*111.58 kg*
A =	*4.32 in*	=	*109.73 mm*
B =	*12 in*	=	*304.80 mm*
C =	*26.7 in*	=	*678.18 mm*
D =		=	
E =		=	
F =		=	
G =		=	
H =		=	

Tag Notes

Dimension Notes

- *Accessories not shown.*
- *Weight and dimensions shown are approximate.*
- *Actual valve may vary from image.*

Printed On: 11-May-2010	TYCO PRV²SIZE Software Version 2.0.3728.17257	Sheet 5 of 5

```
{Relief valve calculation to determine the as installed capacity of the LAPD tank relief valve for internal pressure}
{The calculation has 3 sections}
{1 - the piping from the tank to the relief valve}
{2 - the relief valve itself}
{3 - the vent piping connected to the relief valve}
{the name plate capacity is 5271 SCFM Air for external pressure, the inlet and vent piping reduce this capacity}

{-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------}

{1 - relief_valve_inlet}
{tank at P0, relief valve inlet at P1}

w_lb_sec^2  = (    (144*g*(A_inlet_ft2^2) )   /   ( Vbar1_inlet_ft3_lb * (f_ci_inlet*L_eq_inlet_ft/D_inlet_ft+ 2 *LN(P0/P1)   )  ) * (  (P0^2 - P1^2)/ P0   ) )

Vbar1_inlet_ft3_lb =Volume(Air,T=T_F,P=P0)

D_inlet_ft = (8 - 2*0.120)/12

A_inlet_ft2 = (PI/4)*(D_inlet_ft^2)

{Colebrook equation which offers an implicit iterative solution for the turbulent friction factor}
1/SQRT(f_ci_inlet) = -2.0*log10(epsilon/(3.7*D_inlet_ft)  +  2.51/(Re_inlet*SQRT(f_ci_inlet)  )  )

{Reynolds # calcs for f}
Re_inlet = 6.31*WCAP/(dsmall_inlet*mu)
dsmall_inlet = D_inlet_ft *12  {internal diameter of pipe in inches}

P0 = 14.4 + 3*1.1

{Resistance coefficients from Crane 410 }
K410inlet =  f_ci_inlet*L_inlet_ft/D_inlet_ft  {straight pipe} + K_inlet  {pipe entrance}      {K is unitless}

K_inlet = 0.78  {entrance pressure drop factor}

L_inlet_ft = 51.89/12

{calculate the equivalent length l that includes the tees, elbows, and inlet between the vessel and relief valve piping}
K410inlet = f_ci_inlet*L_eq_inlet_ft/D_inlet_ft

{Colebrook equation for the turbulent friction factor, Crane 410 equation 1-20, set Reynolds number to 1E8 to get a fully turbulent friction factor f_T}
1/SQRT(f_T_inlet) = -2.0*log10(epsilon/(3.7*D_inlet_ft)  +  2.51/(Re_f_T_inlet*SQRT(f_T_inlet)  )  )
Re_f_T_inlet = 1E8  {A large Reynolds number is input to get the fully turbulent friction factor}

DELTAP_inlet_psid = P0 - P1   {flow pressure drop psi}

{check}
DELTAP_DARCY_inlet_check = (3.3591E-6)*(f_ci_inlet*L_eq_inlet_ft*WCAP^2)/(rho_inlet*dsmall_inlet^5)
rho_inlet = Density(Air,T=T_F,P=P0)

{-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------}

{2 - Pressure drop across the relief valve itself}
{relief valve inlet at P1, relief valve outlet at P2}
{This sheet calculates relief valve sizing based upon US volumetric flow units for Pilot Operated Relief Valves}
{This is for the pressure case for a 9300 series}

A = V*SQRT(M*T*Z) / (4645*K_d*P1*F)  {U.S. Volumetric Flow (SCF) Formula 11}
```

A = 28.89 *{orifice area in^2}*

F = SQRT((k/(k-1)) * ((P2/P1)^(2/k) - (P2/P1)^((k+1)/k))) *{relief valve subsonic flow factor based on the ratio of specfic heats and pressure drop across the valve}*

k = 1.4 *{ratio of specific heats}*

P2 = P1p *{pressure at valve outlet during flow, 14.7 psia + back pressure}*

M = 29 *{molecular weight of the flowing gas}*

T = 519.67 *{R, Absolute relieving temperature, 519.67 R = 60 F}*

Z = 1 *{compressibility factor}*

K_d = 0.650*(P2/P1)^(-0.349) *{subsonic valve coefficient to be used when the set pressure is less than 15 psig}*

DELTAP_relief_psid = P1 - P2 *{flow pressure drop psi}*

{--}
{3 - Pressure drop from the relief valve outlet to the vent outlet}
{P1p is the relief valve outlet, P2P is atmospheric pressure}

flow_rate_ft3_min = flow_rate_ft3_hr /60

flow_rate_ft3_min = V

{full compressible isothermal equation 1-27 from Crane 410 }
{look at what diameter tube is necessary to take argon from the supply to the tank}
w_lb_sec^2 = ((144*g*(A_vent_ft2^2)) / (Vbar1_vent_ft3_lb * (f_ci_vent*L_eq_vent_ft/D_vent_ft+ 2 *LN(P1p/P2p))) * ((P1p^2 - P2p^2)/ P1p))

P2p = 14.4 *{psi, atmospheric pressure}*

L_vent_ft = 8 *{length of purge supply tubing in ft}*

g = 32.174 *{gravity ft/sec^2}*

A_vent_ft2 = (PI/4)*(D_vent_ft^2) *{cross sectional area of supply tubing ft^2}*

D_vent_ft = 8.329/12 *{conver tube ID from inches to feet}*

DELTAP_vent_psid = P1p - P2p *{flow pressure drop psi}*

{specific volume of the argon tank purge}
Vbar1_vent_ft3_lb =Volume(Air,T=T_F,P=P1p)

Vbar_stp_ft3_lb = Volume(Air,T=T_F,P=14.7)

T_F = 60 *{deg. F}*

w_lb_sec = flow_rate_ft3_hr / (Vbar_stp_ft3_lb*3600) *{ft^3/hr * lb/ft^3 * 1 hr/ 3600 sec}* *{convert SCFH to lb/sec}*

{Reynolds # calcs for f}
Re_vent = 6.31*WCAP/(dsmall_vent*mu)

WCAP = w_lb_sec * 3600 *{lb/ hr, converted from lb/sec}*

dsmall_vent = D_vent_ft*12 *{internal diameter of pipe in inches}*

mu=Viscosity(Air,T=T_F)/2.42 *{cp, converted from lb/ft-hr}*

{Colebrook equation which offers an implicit iterative solution for the turbulent friction factor}
1/SQRT(f_ci_vent) = -2.0*log10(epsilon/(3.7*D_vent_ft) + 2.51/(Re_vent*SQRT(f_ci_vent)))

epsilon = 0.00015 *{ft}* *{absolute roughness in feet for drawn tubing = 0.000,005 ft, for commericial steel = 0.00015 ft}*

{Resistance coefficients from Crane 410 }
K410_vent = num_elbows_vent*14*f_T_vent *{elbows}* + f_ci_vent*L_vent_ft/D_vent_ft *{straight pipe}* + 1.0 *{pipe exit}* *{K is unitless}*

{calculate the equivalent length l that includes the tees, elbows, and inlet between the vessel and relief valve piping}
K410_vent = f_ci_vent*L_eq_vent_ft/D_vent_ft

{Colebrook equation for the turbulent friction factor, Crane 410 equation 1-20, set Reynolds number to 1E8 to get a fully turbulent friction factor f_T}
1/SQRT(f_T_vent) = -2.0*log10(epsilon/(3.7*D_vent_ft) + 2.51/(Re_f_T_vent*SQRT(f_T_vent)))
Re_f_T_vent = 1E8 *{A large Reynolds number is input to get the fully turbulent friction factor}*

num_elbows_vent = 5 *{number of elbows in the path from the vessel to the relief valve}*

{check}
DELTAP_DARCY_vent_check = (3.3591E-6)*(f_ci_vent*L_eq_vent_ft*WCAP^2)/(rho_vent*dsmall_vent^5)
rho_vent = Density(Air,T=T_F,P=P1p)

$$w_{lb,sec}^2 = \frac{144 \cdot g \cdot A_{inlet,ft2}^2}{Vbar1_{inlet,ft3,lb} \cdot \left[f_{ci,inlet} \cdot \frac{L_{eq,inlet,ft}}{D_{inlet,ft}} + 2 \cdot \ln\left(\frac{P0}{P1}\right)\right]} \cdot \left[\frac{P0^2 - P1^2}{P0}\right]$$

$$Vbar1_{inlet,ft3,lb} = \mathbf{v}\left['Air', T = T_F, P = P0\right]$$

$$D_{inlet,ft} = \frac{8 - 2 \cdot 0.12}{12}$$

$$A_{inlet,ft2} = \frac{\pi}{4} \cdot D_{inlet,ft}^2$$

$$\frac{1}{\sqrt{f_{ci,inlet}}} = -2 \cdot \log\left[\frac{\varepsilon}{3.7 \cdot D_{inlet,ft}} + \frac{2.51}{Re_{inlet} \cdot \sqrt{f_{ci,inlet}}}\right]$$

$$Re_{inlet} = 6.31 \cdot \frac{WCAP}{dsmall_{inlet} \cdot \mu}$$

$$dsmall_{inlet} = D_{inlet,ft} \cdot 12$$

$$P0 = 14.4 + 3 \cdot 1.1$$

$$K410inlet = f_{ci,inlet} \cdot \frac{L_{inlet,ft}}{D_{inlet,ft}} + K_{inlet}$$

$$K_{inlet} = 0.78$$

$$L_{inlet,ft} = \frac{51.89}{12}$$

$$K410inlet = f_{ci,inlet} \cdot \frac{L_{eq,inlet,ft}}{D_{inlet,ft}}$$

$$\frac{1}{\sqrt{f_{T,inlet}}} = -2 \cdot \textbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{inlet,ft}} + \frac{2.51}{Re_{f,T,inlet} \cdot \sqrt{f_{T,inlet}}}\right]$$

$$Re_{f,T,inlet} = 1 \times 10^{8}$$

$$\Delta P_{inlet,psid} = P0 - P1$$

$$\Delta P_{DARCY,inlet,check} = 0.0000033591 \cdot \frac{f_{ci,inlet} \cdot L_{eq,inlet,ft} \cdot WCAP^{2}}{\rho_{inlet} \cdot dsmall_{inlet}^{5}}$$

$$\rho_{inlet} = \rho\left[\text{'Air'}, T = T_F, P = P0\right]$$

$$A = V \cdot \frac{\sqrt{M \cdot T \cdot Z}}{4645 \cdot K_d \cdot P1 \cdot F}$$

$$A = 28.89$$

$$F = \sqrt{\left[\frac{k}{k-1}\right] \cdot \left[\left(\frac{P2}{P1}\right)^{\left(\frac{2}{k}\right)} - \left(\frac{P2}{P1}\right)^{\left(\frac{k+1}{k}\right)}\right]}$$

$$k = 1.4$$

$$P2 = P1p$$

$$M = 29$$

$$T = 519.67$$

$$Z = 1$$

$$K_d = 0.65 \cdot \left[\frac{P2}{P1}\right]^{-0.349}$$

$$\Delta P_{relief,psid} = P1 - P2$$

$$flow_{rate,ft3,min} = \frac{flow_{rate,ft3,hr}}{60}$$

$$flow_{rate,ft3,min} = V$$

$$w_{lb,sec}^{2} = \frac{144 \cdot g \cdot A_{vent,ft2}^{2}}{Vbar1_{vent,ft3,lb} \cdot \left[f_{ci,vent} \cdot \frac{L_{eq,vent,ft}}{D_{vent,ft}} + 2 \cdot \textbf{ln}\left(\frac{P1p}{P2p}\right)\right]} \cdot \left[\frac{P1p^{2} - P2p^{2}}{P1p}\right]$$

$$P2p = 14.4$$

$$L_{vent,ft} = 8$$

$$g = 32.174$$

$$A_{vent,ft2} = \frac{\pi}{4} \cdot D_{vent,ft}^{\ 2}$$

$$D_{vent,ft} = \frac{8.329}{12}$$

$$\Delta P_{vent,psid} = P1p - P2p$$

$$Vbar1_{vent,ft3,lb} = \mathbf{v}\left[\text{'Air'}, T = T_F, P = P1p\right]$$

$$Vbar_{stp,ft3,lb} = \mathbf{v}\left[\text{'Air'}, T = T_F, P = 14.7\right]$$

$$T_F = 60$$

$$w_{lb,sec} = \frac{flow_{rate,ft3,hr}}{Vbar_{stp,ft3,lb} \cdot 3600}$$

$$Re_{vent} = 6.31 \cdot \frac{WCAP}{dsmall_{vent} \cdot \mu}$$

$$WCAP = w_{lb,sec} \cdot 3600$$

$$dsmall_{vent} = D_{vent,ft} \cdot 12$$

$$\mu = \frac{\mathbf{Visc}\left[\text{'Air'}, T = T_F\right]}{2.42}$$

$$\frac{1}{\sqrt{f_{ci,vent}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{vent,ft}} + \frac{2.51}{Re_{vent} \cdot \sqrt{f_{ci,vent}}}\right]$$

$$\varepsilon = 0.00015$$

$$K410_{vent} = num_{elbows,vent} \cdot 14 \cdot f_{T,vent} + f_{ci,vent} \cdot \frac{L_{vent,ft}}{D_{vent,ft}} + 1$$

$$K410_{vent} = f_{ci,vent} \cdot \frac{L_{eq,vent,ft}}{D_{vent,ft}}$$

$$\frac{1}{\sqrt{f_{T,vent}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{vent,ft}} + \frac{2.51}{Re_{f,T,vent} \cdot \sqrt{f_{T,vent}}}\right]$$

$$Re_{f,T,vent} = 1 \times 10^{8}$$

$$num_{elbows,vent} = 5$$

$$\Delta P_{DARCY,vent,check} = 0.0000033591 \cdot \frac{f_{ci,vent} \cdot L_{eq,vent,ft} \cdot WCAP^2}{\rho_{vent} \cdot dsmall_{vent}^{\ 5}}$$

$$\rho_{vent} = \rho\left[\text{'Air'}, T = T_F, P = P1p\right]$$

SOLUTION

Unit Settings: [F]/[psia]/[lbm]/[degrees]

$A = 28.89$ [in^2]

$A_{vent,ft2} = 0.3784$ [ft^2]

$\Delta P_{DARCY,vent,check} = 0.6417$

$A_{inlet,ft2} = 0.3284$ [ft^2]

$\Delta P_{DARCY,inlet,check} = 0.2974$

$\Delta P_{inlet,psid} = 0.3122$ [psid]

$\Delta P_{relief,psid}$ = 2.303 [psid]
$dsmall_{inlet}$ = 7.76 [in]
$D_{inlet,ft}$ = 0.6467 [ft]
ε = 0.00015 [ft]
$flow_{rate,ft3,hr}$ = 262605 [SCFH]
$f_{ci,inlet}$ = 0.015099
$f_{T,inlet}$ = 0.01416
g = 32.17 [ft/s^2]
K410inlet = 0.881 [ ]
K_d = 0.683
$L_{eq,inlet,ft}$ = 37.73 [ft]
$L_{inlet,ft}$ = 4.324 [ft]
M = 29
$num_{elbows,vent}$ = 5
P1 = 17.388 [psia]
P2 = 15.085 [psia]
$Re_{f,T,inlet}$ = 1.000E+08
Re_{inlet} = 904022.700
ρ_{inlet} = 0.091937 [lb$_m$/ft^3]
T = 519.7 [R]
V = 4377 [SCFM]
$Vbar1_{vent,ft3,lb}$ = 12.76 [ft^3/lb$_m$]
WCAP = 20051.039 [lb/hr]
Z = 1 [unitless]

$\Delta P_{vent,psid}$ = 0.685 [psid]
$dsmall_{vent}$ = 8.329 [in]
$D_{vent,ft}$ = 0.6941 [ft]
F = 0.3371
$flow_{rate,ft3,min}$ = 4377 [SCFM]
$f_{ci,vent}$ = 0.015001
$f_{T,vent}$ = 0.01396
k = 1.4
$K410_{vent}$ = 2.150049 [ ]
K_{inlet} = 0.78
$L_{eq,vent,ft}$ = 99.48 [ft]
$L_{vent,ft}$ = 8 [ft]
μ = 0.018035 [cp]
P0 = 17.7 [psia]
P1p = 15.085 [psia]
P2p = 14.400 [psia]
$Re_{f,T,vent}$ = 1.000E+08
Re_{vent} = 842263.916 [ ]
ρ_{vent} = 0.07835 [lb$_m$/ft^3]
T_F = 60 [f]
$Vbar1_{inlet,ft3,lb}$ = 10.88 [ft^3/lb$_m$]
$Vbar_{stp,ft3,lb}$ = 13.09680 [ft^3/lbm]
$W_{lb,sec}$ = 5.57 [lb/sec]

17 potential unit problems were detected.
EES suggested units (shown in purple) for rho_vent .

```
{Relief valve calculation to determine the as installed capacity of the LAPD tank relief valve for EXTERNAL PRESSURE}
{The calculation has 3 sections}
{1 - the piping from the tank to the relief valve}
{2 - the relief valve itself}
{3 - the vent piping connected to the relief valve}
{the name plate capacity is 1018 SCFM Air for external pressure, the inlet and vent piping reducee this capacity}

{-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------}
{1 - relief_valve_inlet piping, funtionally the outlet for the vacuum case}
{tank at P0, relief valve inlet at P1, inlet pressure to piping section is P1}

w_lb_sec^2 = (    (144*g*(A_inlet_ft2^2) )   /   ( Vbar1_inlet_ft3_lb * (f_ci_inlet*L_eq_inlet_ft/D_inlet_ft+ 2 *LN(P1/P0)   )   ) * (
  (P1^2 - P0^2)/ P1   ) )  {Crane 410 equation 1-27 for isothermal compressible flow, w in lb/sec}

Vbar1_inlet_ft3_lb =Volume(Air,T=T_F,P=P1)    {specific volume of air ft^3 / lb at the inlet of the piping section}

D_inlet_ft = (8 - 2*0.120)/12    {piping internal diameter, ft}

A_inlet_ft2 = (PI/4)*(D_inlet_ft^2)    {pipng internal flow area, ft^2}

{Colebrook equation which offers an implicit iterative solution for the turbulent friction factor}
1/SQRT(f_ci_inlet) = -2.0*log10(epsilon/(3.7*D_inlet_ft)   +   2.51/(Re_inlet*SQRT(f_ci_inlet)   )   )

{Reynolds # calcs for f}
Re_inlet = 6.31*WCAP/(dsmall_inlet*mu)
dsmall_inlet = D_inlet_ft *12  {internal diameter of pipe in inches}

P0 = 14.4 - 0.2   {Tank maximum external pressure is 0.2 psid}

{Resistance coefficients from Crane 410 }
K410inlet =  f_ci_inlet*L_inlet_ft/D_inlet_ft  {straight pipe} + K_inlet  {pipe entrance}      {K is unitless}

K_inlet = 1.0 { for the vaccum case this is a pipe outlet entrance pressure drop factor}

L_inlet_ft = 51.89/12   {physical length of the inlet piping, ft}

{calculate the equivalent length L_eq_inlet_Ft that includes the tees, elbows, and inlet between the vessel and relief valve piping}
K410inlet = f_ci_inlet*L_eq_inlet_ft/D_inlet_ft

{Colebrook equation for the turbulent friction factor, Crane 410 equation 1-20, set Reynolds number to 1E8 to get a fully turbulent
friction factor f_T}
1/SQRT(f_T_inlet) = -2.0*log10(epsilon/(3.7*D_inlet_ft)   +   2.51/(Re_f_T_inlet*SQRT(f_T_inlet)   )   )
Re_f_T_inlet = 1E8  {A large Reynolds number is input to get the fully turbulent friction factor}

DELTAP_inlet_psid = P1- P0  {flow pressure drop for this piping section psi}

{check against the simple Darcy equation}
DELTAP_DARCY_inlet_check = (3.3591E-6)*(f_ci_inlet*L_eq_inlet_ft*WCAP^2)/(rho_inlet*dsmall_inlet^5)
rho_inlet = Density(Air,T=T_F,P=P1)

{-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------}

{2 - Pressure drop across the relief valve itself}
{relief valve inlet at P1, relief valve outlet at P2, for vacuum P2 is the functional inlet and P1 the functional outlet}
{This sheet calculates relief valve sizing based upon US volumetric flow units for Pilot Operated Relief Valves}
{This is for the pressure case for a 9300 series}

A = V*SQRT(M*T*Z) / (4645*K_d*P2*F)   {U.S. Volumetric Flow (SCF) Formula 11}
```

A = 28.89 *{orifice area in^2}*

F = SQRT((k/(k-1)) * ((P1/P2)^(2/k) - (P1/P2)^((k+1)/k))) *{relief valve subsonic flow factor based on the ratio of specfic heats and pressure drop across the valve}*

k = 1.4 *{ratio of specific heats}*

M = 29 *{molecular weight of the flowing gas}*

T = 519.67 *{R, Absolute relieving temperature, 519.67 R = 60 F}*

Z = 1 *{compressibility factor}*

K_d = 0.55 *{subsonic valve coefficient for vacuum}*

DELTAP_relief_psid = P2 - P1 *{flow pressure drop psi}*

{---}
{3 - Pressure drop from the vent piping physical outlet (inlet for the external pressure case) to the relief valve dishcharge (relief valve inlet for the external pressure case}
{P1p is the relief valve outlet, P2P is atmospheric pressure, for the vacuum case P1p is functionally the vent outlet and P2p functionally the vent inlet}

flow_rate_ft3_min = flow_rate_ft3_hr /60

flow_rate_ft3_min = V

{full compressible isothermal equation 1-27 from Crane 410 }
{look at what diameter tube is necessary to take argon from the supply to the tank}
w_lb_sec^2 = ((144*g*(A_vent_ft2^2)) / (Vbar1_vent_ft3_lb * (f_ci_vent*L_eq_vent_ft/D_vent_ft+ 2 *LN(P2p/P1p))) * ((P2p^2 - P1p^2)/ P2p))

P2 = P1p

P2p = 14.4 *{psi, atmospheric pressure}*

L_vent_ft = 8 *{length of purge supply tubing in ft}*

g = 32.174 *{gravity ft/sec^2}*

A_vent_ft2 = (PI/4)*(D_vent_ft^2) *{cross sectional area of supply tubing ft^2}*

D_vent_ft = 8.329/12 *{conver tube ID from inches to feet}*

DELTAP_vent_psid = P2p - P1p *{flow pressure drop psi}*

{specific volume of the argon tank purge}
Vbar1_vent_ft3_lb =Volume(Air,T=T_F,P=P2p)

Vbar_stp_ft3_lb = Volume(Air,T=T_F,P=14.7)

T_F = 60 *{deg. F}*

w_lb_sec = flow_rate_ft3_hr / (Vbar_stp_ft3_lb*3600) *{ft^3/hr * lb/ft^3 * 1 hr/ 3600 sec}* *{relationship between SCFM and lb/sec}*

{Reynolds # calcs for f}
Re_vent = 6.31*WCAP/(dsmall_vent*mu)

WCAP = w_lb_sec * 3600 *{lb/ hr, converted from lb/sec}*

dsmall_vent = D_vent_ft*12 *{internal diameter of pipe in inches}*

mu=Viscosity(Air,T=60)/2.42 *{cp, converted from lb/ft-hr}*

{Colebrook equation which offers an implicit iterative solution for the turbulent friction factor}
1/SQRT(f_ci_vent) = -2.0*log10(epsilon/(3.7*D_vent_ft) + 2.51/(Re_vent*SQRT(f_ci_vent)))

epsilon = 0.00015 *{ft}* *{absolute roughness in feet for drawn tubing = 0.000,005 {ft}, for commericial steel = 0.00015 {ft} }*

{Resistance coefficients from Crane 410 }
K410_vent = num_elbows_vent*14*f_T_vent *{elbows}* + f_ci_vent*L_vent_ft/D_vent_ft *{straight pipe}* + 0.78 *{VACUUM case pipe inlet}* *{K is unitless}*

{calculate the equivalent length l that includes the tees, elbows, and inlet between the vessel and relief valve piping}
K410_vent = f_ci_vent*L_eq_vent_ft/D_vent_ft

{Colebrook equation for the turbulent friction factor, Crane 410 equation 1-20, set Reynolds number to 1E8 to get a fully turbulent friction factor f_T}
1/SQRT(f_T_vent) = -2.0*log10(epsilon/(3.7*D_vent_ft) + 2.51/(Re_f_T_vent*SQRT(f_T_vent)))
Re_f_T_vent = 1E8 *{A large Reynolds number is input to get the fully turbulent friction factor}*

num_elbows_vent = 5 *{number of elbows in the path from the vessel to the relief valve}*

{check against the simple Darcy equation}
DELTAP_DARCY_vent_check = (3.3591E-6)*(f_ci_vent*L_eq_vent_ft*WCAP^2)/(rho_vent*dsmall_vent^5)
rho_vent = Density(Air,T=T_F,P=P2p)

$$w_{lb,sec}^{2} = \frac{144 \cdot g \cdot A_{inlet,ft2}^{2}}{Vbar1_{inlet,ft3,lb} \cdot \left[f_{ci,inlet} \cdot \frac{L_{eq,inlet,ft}}{D_{inlet,ft}} + 2 \cdot \ln\left(\frac{P1}{P0}\right)\right]} \cdot \left[\frac{P1^{2} - P0^{2}}{P1}\right]$$

$$Vbar1_{inlet,ft3,lb} = \mathbf{v}\left[\text{'Air'}, T = T_F, P = P1\right]$$

$$D_{inlet,ft} = \frac{8 - 2 \cdot 0.12}{12}$$

$$A_{inlet,ft2} = \frac{\pi}{4} \cdot D_{inlet,ft}^{2}$$

$$\frac{1}{\sqrt{f_{ci,inlet}}} = -2 \cdot \log\left[\frac{\varepsilon}{3.7 \cdot D_{inlet,ft}} + \frac{2.51}{Re_{inlet} \cdot \sqrt{f_{ci,inlet}}}\right]$$

$$Re_{inlet} = 6.31 \cdot \frac{WCAP}{dsmall_{inlet} \cdot \mu}$$

$$dsmall_{inlet} = D_{inlet,ft} \cdot 12$$

$$P0 = 14.4 - 0.2$$

$$K410inlet = f_{ci,inlet} \cdot \frac{L_{inlet,ft}}{D_{inlet,ft}} + K_{inlet}$$

$$K_{inlet} = 1$$

$$L_{inlet,ft} = \frac{51.89}{12}$$

$$K410inlet = f_{ci,inlet} \cdot \frac{L_{eq,inlet,ft}}{D_{inlet,ft}}$$

$$\frac{1}{\sqrt{f_{T,inlet}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{inlet,ft}} + \frac{2.51}{Re_{f,T,inlet} \cdot \sqrt{f_{T,inlet}}}\right]$$

$$Re_{f,T,inlet} = 1 \times 10^{8}$$

$$\Delta P_{inlet,psid} = P1 - P0$$

$$\Delta P_{DARCY,inlet,check} = 0.0000033591 \cdot \frac{f_{ci,inlet} \cdot L_{eq,inlet,ft} \cdot WCAP^2}{\rho_{inlet} \cdot dsmall_{inlet}^{5}}$$

$$\rho_{inlet} = \rho\left[\text{'Air'}, T = T_F, P = P1\right]$$

$$A = V \cdot \frac{\sqrt{M \cdot T \cdot Z}}{4645 \cdot K_d \cdot P2 \cdot F}$$

$$A = 28.89$$

$$F = \sqrt{\left[\frac{k}{k-1}\right] \cdot \left[\left(\frac{P1}{P2}\right)^{\left(\frac{2}{k}\right)} - \left(\frac{P1}{P2}\right)^{\left(\frac{k+1}{k}\right)}\right]}$$

$$k = 1.4$$

$$M = 29$$

$$T = 519.67$$

$$Z = 1$$

$$K_d = 0.55$$

$$\Delta P_{relief,psid} = P2 - P1$$

$$flow_{rate,ft3,min} = \frac{flow_{rate,ft3,hr}}{60}$$

$$flow_{rate,ft3,min} = V$$

$$w_{lb,sec}^{2} = \frac{144 \cdot g \cdot A_{vent,ft2}^{2}}{Vbar1_{vent,ft3,lb} \cdot \left[f_{ci,vent} \cdot \frac{L_{eq,vent,ft}}{D_{vent,ft}} + 2 \cdot \mathbf{ln}\left(\frac{P2p}{P1p}\right)\right]} \cdot \left[\frac{P2p^2 - P1p^2}{P2p}\right]$$

$$P2 = P1p$$

$$P2p = 14.4$$

$$L_{vent,ft} = 8$$

$$g = 32.174$$

$$A_{vent,ft2} = \frac{\pi}{4} \cdot D_{vent,ft}^{2}$$

$$D_{vent,ft} = \frac{8.329}{12}$$

$$\Delta P_{vent,psid} = P2p - P1p$$

$$Vbar1_{vent,ft3,lb} = \mathbf{v}\left['Air' , T = T_F , P = P2p \right]$$

$$Vbar_{stp,ft3,lb} = \mathbf{v}\left['Air' , T = T_F , P = 14.7 \right]$$

$$T_F = 60$$

$$w_{lb,sec} = \frac{flow_{rate,ft3,hr}}{Vbar_{stp,ft3,lb} \cdot 3600}$$

$$Re_{vent} = 6.31 \cdot \frac{WCAP}{dsmall_{vent} \cdot \mu}$$

$$WCAP = w_{lb,sec} \cdot 3600$$

$$dsmall_{vent} = D_{vent,ft} \cdot 12$$

$$\mu = \frac{\mathbf{Visc}\left['Air' , T = 60 \right]}{2.42}$$

$$\frac{1}{\sqrt{f_{ci,vent}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{vent,ft}} + \frac{2.51}{Re_{vent} \cdot \sqrt{f_{ci,vent}}} \right]$$

$$\varepsilon = 0.00015$$

$$K410_{vent} = num_{elbows,vent} \cdot 14 \cdot f_{T,vent} + f_{ci,vent} \cdot \frac{L_{vent,ft}}{D_{vent,ft}} + 0.78$$

$$K410_{vent} = f_{ci,vent} \cdot \frac{L_{eq,vent,ft}}{D_{vent,ft}}$$

$$\frac{1}{\sqrt{f_{T,vent}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{vent,ft}} + \frac{2.51}{Re_{f,T,vent} \cdot \sqrt{f_{T,vent}}} \right]$$

$$Re_{f,T,vent} = 1 \times 10^{8}$$

$$num_{elbows,vent} = 5$$

$$\Delta P_{DARCY,vent,check} = 0.0000033591 \cdot \frac{f_{ci,vent} \cdot L_{eq,vent,ft} \cdot WCAP^{2}}{\rho_{vent} \cdot dsmall_{vent}^{5}}$$

$$\rho_{vent} = \rho\left['Air' , T = T_F , P = P2p \right]$$

SOLUTION

Unit Settings: [F]/[psia]/[lbm]/[degrees]

$A = 28.89$ [in^2]

$A_{inlet,ft2} = 0.3284$ [ft^2]

$A_{vent,ft2} = 0.3784$ [ft^2]

$\Delta P_{DARCY,inlet,check} = 0.0195$

$\Delta P_{DARCY,vent,check} = 0.02545$

$\Delta P_{inlet,psid} = 0.01956$ [psid]

$\Delta P_{relief,psid} = 0.1549$ [psid]

$\Delta P_{vent,psid} = 0.02552$ [psid]

$dsmall_{inlet} = 7.76$ [in]

$dsmall_{vent} = 8.329$ [in]

$D_{inlet,ft}$ = 0.6467 [ft]
ε = 0.00015 [ft]
$flow_{rate,ft3,hr}$ = 53520 [SCFH]
$f_{ci,inlet}$ = 0.01749
$f_{T,inlet}$ = 0.01416
g = 32.17 [ft/s^2]
K410inlet = 1.117 [ ]
K_d = 0.55
$L_{eq,inlet,ft}$ = 41.3 [ft]
$L_{inlet,ft}$ = 4.324 [ft]
M = 29
$num_{elbows,vent}$ = 5
P1 = 14.220 [psia]
P2 = 14.374 [psia]
$Re_{f,T,inlet}$ = 1.000E+08
Re_{inlet} = 184246
ρ_{inlet} = 0.07386 [lb$_m$/ft^3]
T = 519.7 [R]
V = 892 [SCFM]
$Vbar1_{vent,ft3,lb}$ = 13.37 [ft^3/lb$_m$]
WCAP = 4087 [lb/hr]
Z = 1 [unitless]

$D_{vent,ft}$ = 0.6941 [ft]
F = 0.1032
$flow_{rate,ft3,min}$ = 892 [SCFM]
$f_{ci,vent}$ = 0.01756
$f_{T,vent}$ = 0.01396
k = 1.4
$K410_{vent}$ = 1.96 [ ]
K_{inlet} = 1
$L_{eq,vent,ft}$ = 77.44 [ft]
$L_{vent,ft}$ = 8 [ft]
μ = 0.01804 [cp]
P0 = 14.2 [psia]
P1p = 14.374 [psia]
P2p = 14.400 [psia]
$Re_{f,T,vent}$ = 1.000E+08
Re_{vent} = 171659 [ ]
ρ_{vent} = 0.0748 [lb$_m$/ft^3]
T_F = 60 [f]
$Vbar1_{inlet,ft3,lb}$ = 13.54 [ft^3/lb$_m$]
$Vbar_{stp,ft3,lb}$ = 13.1 [ft^3/lbm]
$w_{lb,sec}$ = 1.135 [lb/sec]

17 potential unit problems were detected.
EES suggested units (shown in purple) for rho_inlet rho_vent .

{this sheet calculates the maximum flow of liquid argon into the LAPD tank during filling}
{the calculation assumes the flow is all liquid - this is conservative because ambient heat input and pressure drop (flashing) would create vapor which would reduce the mass flow rate}

{P1p = 100+ 14.4} *{fill line inlet pressure, psia}*

elevation_head_psi = (336/12)*rho_fill/144 *{pressure head due to elevation, psi}*

P2p = 14.4 +1.1*3 *{Tank maximum pressure, psia}*

{P1p = P2p + 50 }

L_fill_Cu_ft = (485 + 60 + 96 + 137+108)/12 *{Type K pre-insulated copper length}* *{+ 498/12* *{1 inch sch 10 length}* *{linear length of fill line pipe in ft}* *}*

K_fill_Cu_pipe = f_ci_fill_Cu*L_fill_Cu_ft/D_fill_Cu_ft *{resistance of the 1"* Type K Cu straight pipe itself}

g = 32.174 *{gravity ft/sec^2}*

A_fill_Cu_ft2 = (PI/4)*(D_fill_Cu_ft^2) *{cross sectional area of the 1"* Type K copper supply pipe ft^2}

D_fill_Cu_ft = 0.995/12 *{convert ID from inches to feet}*

DELTAP_fill_psid = P1p - P2p *{flow pressure drop psi}*

{---}

{For the 1" SCH 10 SS pipe from the fill tank to the pump discharge - this is not the intended fill path but is the path of least resistance to the tank}
L_fill_SS_ft = 498/12 *{1 inch sch 10 length}* *{linear length of fill line pipe in ft}*

K_fill_SS_pipe = f_ci_fill_SS*L_fill_SS_ft/D_fill_SS_ft *{resistance of the 1"* sch 10 straight pipe itself}

A_fill_SS_ft2 = (PI/4)*(D_fill_SS_ft^2) *{cross sectional area of 1"* SCH 10 supply pipe ft^2}

D_fill_SS_ft = 1.097/12 *{convert ID from inches to feet}*

{Reynolds # calcs for f}
Re_fill_SS = 6.31*WCAP/(dsmall_fill_SS*mu)

dsmall_fill_SS = D_fill_SS_ft*12 *{internal diameter of pipe in inches}*

{calculate the equivalent length l that includes the tees, elbows, and inlet between the vessel and relief valve piping}
*{K410_fill_SS = f_ci_fill_SS*L_eq_fill_SS_ft/D_fill_SS_ft }*

{Colebrook equation which offers an implicit iterative solution for the turbulent friction factor}
1/SQRT(f_ci_fill_SS) = -2.0*log10(epsilon/(3.7*D_fill_SS_ft) + 2.51/(Re_fill_SS*SQRT(f_ci_fill_SS)))

{Resistance coefficients from Crane 410 }
K410_fill_SS = num_elbows_fill_SS*K_elbow_fill_SS *{elbows}* + K_fill_SS_pipe *{straight pipe}*
K_elbow_fill_SS = 20*f_T_fill_SS

num_elbows_fill_SS = 14 *{number of elbows in the SS line, flows thru the branches of tees are counted as elbows because the elbow is less restrictive}*

{Colebrook equation for the turbulent friction factor, Crane 410 equation 1-20, set Reynolds number to 1E8 to get a fully turbulent friction factor f_T}
1/SQRT(f_T_fill_SS) = -2.0*log10(epsilon/(3.7*D_fill_SS_ft) + 2.51/(Re_f_T_fill_SS*SQRT(f_T_fill_SS)))
Re_f_T_fill_SS = 1E8 *{A large Renolds number is input to get the fully turbulent friction factor}*

K410_SS_to_Cu = K410_fill_SS*(dsmall_fill_Cu/dsmall_fill_SS)^4 *{convert the SS pipe resistance to equivalent copper pipe resistance}*
{Ka = Kb(da/db)^4}*
{---}

{specific volume of the argon liquid at the supply piping inlet}
Vbar1_fill_ft3_lb =Volume(Argon,x=0,P=P1p)

{Reynolds # calcs for f}
Re_fill_Cu = 6.31*WCAP/(dsmall_fill_Cu*mu)

WCAP = w_lb_sec * 3600 *{mass flow in lb/ hr, converted from lb/sec}*

dsmall_fill_Cu = D_fill_Cu_ft*12 *{internal diameter of pipe in inches}*

mu=Viscosity(Argon,x=0,P=P_average)/2.42 *{liquid argon viscosity, cp, converted from lb/ft-hr by dividing by 2.42}*

{Colebrook equation which offers an implicit iterative solution for the turbulent friction factor}
1/SQRT(f_ci_fill_Cu) = -2.0*log10(epsilon/(3.7*D_fill_Cu_ft) + 2.51/(Re_fill_Cu*SQRT(f_ci_fill_Cu)))

epsilon = 0.00015 *{ft}* *{absolute roughness in feet for drawn tubing = 0.000,005, for commericial steel = 0.00015}*

{Resistance coefficients from Crane 410 }
K410_fill_Cu = num_elbows_fill_Cu*K_elbow_fill_Cu *{elbows}* + K_fill_Cu_pipe *{straight pipe}* + K_pipe_exit *{pipe exit}* + K_valve_cryolab + K_valve_eden_Y + 2*K_valve_eden_globe + K410_SS_to_Cu

K_pipe_exit = 1.0

K_elbow_fill_Cu = 20*f_T_fill_Cu *{resistance for an individual elbow}*

num_elbows_fill_Cu = 3 *{type K}*

{+ 14 {1" sch 10 , this counts both elbows and tees for ss, this is conservative for this calc because tees have more resistance than elbows in this instance} {number of elbows in the path from the vessel to the relief valve} }

{convert the mfg valve Cv values to K values}
K_valve_cryolab = 890.3*(dsmall_fill_Cu^4)/Cv_cryolab^2 *{Cryolab valve on the fill line}*
Cv_cryolab = 15.2

K_valve_eden_Y = 890.3*(dsmall_fill_Cu^4)/Cv_eden_Y^2 *{Eden Y valve on the ss piping}*
Cv_eden_Y = 27

K_valve_eden_globe = 890.3*(dsmall_fill_Cu^4)/Cv_eden_globe^2 *{Eden globe valve on the ss piping}*
Cv_eden_globe = 18

{calculate the equivalent length l that includes the tees, elbows, and inlet between the vessel and relief valve piping}
K410_fill_Cu = f_ci_fill_Cu*L_eq_fill_Cu_ft/D_fill_Cu_ft

{Colebrook equation for the turbulent friction factor, Crane 410 equation 1-20, set Reynolds number to 1E8 to get a fully turbulent friction factor f_T}
1/SQRT(f_T_fill_Cu) = -2.0*log10(epsilon/(3.7*D_fill_Cu_ft) + 2.51/(Re_f_T_fill_Cu*SQRT(f_T_fill_Cu)))
Re_f_T_fill_Cu = 1E8 *{A large Renolds number is input to get the fully turbulent friction factor}*

{Pressure drop acordding to Crane equation 6-8 page 6-3}
DELTAP_tank_fill_line = (3.3591E-6)*(f_ci_fill_Cu*L_eq_fill_Cu_ft*WCAP^2)/(rho_fill*dsmall_fill_Cu^5)

rho_fill = Density(Argon,x=0,P=P_average) *{density of liquid argon saturated at the inlet supply pressure}*

P_average = (P1p + P2p)/2

(P1p - P2p) = DELTAP_tank_fill_line

GPM_equivalent = WCAP *{lb / hr}* * (1/60) *{1 hr / 60 min}* * (1 / 11.63) *{ 1 gal / 11.63 lb lar}*

{check of the velocity in the pipe}
velocity_ft_sec = 0.16*WCAP / (rho_fill * PI *dsmall_fill_Cu^2) *{velocity of the flow in ft/sec}*

{mass flow rate in pounds per hours}
WCAP=23556

{Equation D.37 from API 2000 section D.9 allows conversion of this argon mass flow to an equivalent air flow}

q_air_SCFH = (x/M_air)*W_fl*SQRT(M_air/T_air)*SQRT(T_i/M)

q_air_SCFM = q_air_SCFH/60

{q_air_SCFM = 4377}

x = 379.46

M_air = 29

W_fl = WCAP

T_air = 519.67

T_i = 519.67

M = 39.948

$$\text{elevation}_{\text{head},\psi} = \frac{336}{12} \cdot \frac{\rho_{\text{fill}}}{144}$$

$$P2p = 14.4 + 1.1 \cdot 3$$

$$L_{\text{fill,Cu,ft}} = \frac{485 + 60 + 96 + 137 + 108}{12}$$

$$K_{\text{fill,Cu,pipe}} = f_{\text{ci,fill,Cu}} \cdot \frac{L_{\text{fill,Cu,ft}}}{D_{\text{fill,Cu,ft}}}$$

$$g = 32.174$$

$$A_{\text{fill,Cu,ft2}} = \frac{\pi}{4} \cdot D_{\text{fill,Cu,ft}}^2$$

$$D_{\text{fill,Cu,ft}} = \frac{0.995}{12}$$

$$\Delta P_{\text{fill,psid}} = P1p - P2p$$

$$L_{\text{fill,SS,ft}} = \frac{498}{12}$$

$$K_{\text{fill,SS,pipe}} = f_{\text{ci,fill,SS}} \cdot \frac{L_{\text{fill,SS,ft}}}{D_{\text{fill,SS,ft}}}$$

$$A_{fill,SS,ft2} = \frac{\pi}{4} \cdot D_{fill,SS,ft}^{2}$$

$$D_{fill,SS,ft} = \frac{1.097}{12}$$

$$Re_{fill,SS} = 6.31 \cdot \frac{WCAP}{dsmall_{fill,SS} \cdot \mu}$$

$$dsmall_{fill,SS} = D_{fill,SS,ft} \cdot 12$$

$$\frac{1}{\sqrt{f_{ci,fill,SS}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{fill,SS,ft}} + \frac{2.51}{Re_{fill,SS} \cdot \sqrt{f_{ci,fill,SS}}}\right]$$

$$K410_{fill,SS} = num_{elbows,fill,SS} \cdot K_{elbow,fill,SS} + K_{fill,SS,pipe}$$

$$K_{elbow,fill,SS} = 20 \cdot f_{T,fill,SS}$$

$$num_{elbows,fill,SS} = 14$$

$$\frac{1}{\sqrt{f_{T,fill,SS}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{fill,SS,ft}} + \frac{2.51}{Re_{f,T,fill,SS} \cdot \sqrt{f_{T,fill,SS}}}\right]$$

$$Re_{f,T,fill,SS} = 1 \times 10^{8}$$

$$K410_{SS,to,Cu} = K410_{fill,SS} \cdot \left[\frac{dsmall_{fill,Cu}}{dsmall_{fill,SS}}\right]^{4}$$

$$Vbar1_{fill,ft3,lb} = \mathbf{v}\left[\text{'Argon'}, x=0, P=P1p\right]$$

$$Re_{fill,Cu} = 6.31 \cdot \frac{WCAP}{dsmall_{fill,Cu} \cdot \mu}$$

$$WCAP = w_{lb,sec} \cdot 3600$$

$$dsmall_{fill,Cu} = D_{fill,Cu,ft} \cdot 12$$

$$\mu = \frac{\mathbf{Visc}\left[\text{'Argon'}, x=0, P=P_{average}\right]}{2.42}$$

$$\frac{1}{\sqrt{f_{ci,fill,Cu}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{fill,Cu,ft}} + \frac{2.51}{Re_{fill,Cu} \cdot \sqrt{f_{ci,fill,Cu}}}\right]$$

$$\varepsilon = 0.00015$$

$$K410_{fill,Cu} = num_{elbows,fill,Cu} \cdot K_{elbow,fill,Cu} + K_{fill,Cu,pipe} + K_{pipe,exit} + K_{valve,cryolab} + K_{valve,eden,Y} + 2 \cdot K_{valve,eden,globe} + K410_{SS,to,Cu}$$

$$K_{pipe,exit} = 1$$

$$K_{elbow,fill,Cu} = 20 \cdot f_{T,fill,Cu}$$

$$num_{elbows,fill,Cu} = 3$$

$$K_{valve,cryolab} = 890.3 \cdot \frac{dsmall_{fill,Cu}^{4}}{Cv_{cryolab}^{2}}$$

$$Cv_{cryolab} = 15.2$$

$$K_{valve,eden,Y} = 890.3 \cdot \frac{dsmall_{fill,Cu}^{\ 4}}{Cv_{eden,Y}^{\ 2}}$$

$$Cv_{eden,Y} = 27$$

$$K_{valve,eden,globe} = 890.3 \cdot \frac{dsmall_{fill,Cu}^{\ 4}}{Cv_{eden,globe}^{\ 2}}$$

$$Cv_{eden,globe} = 18$$

$$K410_{fill,Cu} = f_{ci,fill,Cu} \cdot \frac{L_{eq,fill,Cu,ft}}{D_{fill,Cu,ft}}$$

$$\frac{1}{\sqrt{f_{T,fill,Cu}}} = -2 \cdot \mathbf{log}\left[\frac{\varepsilon}{3.7 \cdot D_{fill,Cu,ft}} + \frac{2.51}{Re_{f,T,fill,Cu} \cdot \sqrt{f_{T,fill,Cu}}}\right]$$

$$Re_{f,T,fill,Cu} = 1 \times 10^{8}$$

$$\Delta P_{tank,fill,line} = 0.0000033591 \cdot \frac{f_{ci,fill,Cu} \cdot L_{eq,fill,Cu,ft} \cdot WCAP^{2}}{\rho_{fill} \cdot dsmall_{fill,Cu}^{\ 5}}$$

$$\rho_{fill} = \rho\left[\text{'Argon'}, x=0, P=P_{average}\right]$$

$$P_{average} = \frac{P1p + P2p}{2}$$

$$P1p - P2p = \Delta P_{tank,fill,line}$$

$$GPM_{equivalent} = WCAP \cdot \frac{1}{60} \cdot \frac{1}{11.63}$$

$$velocity_{ft,sec} = 0.16 \cdot \frac{WCAP}{\rho_{fill} \cdot \pi \cdot dsmall_{fill,Cu}^{\ 2}}$$

$$WCAP = 23556$$

$$q_{air,SCFH} = \frac{x}{M_{air}} \cdot W_{fl} \cdot \sqrt{\frac{M_{air}}{T_{air}}} \cdot \sqrt{\frac{T_i}{M}}$$

$$q_{air,SCFM} = \frac{q_{air,SCFH}}{60}$$

$$x = 379.46$$

$$M_{air} = 29$$

$$W_{fl} = WCAP$$

$$T_{air} = 519.67$$

$$T_i = 519.67$$

$$M = 39.948$$

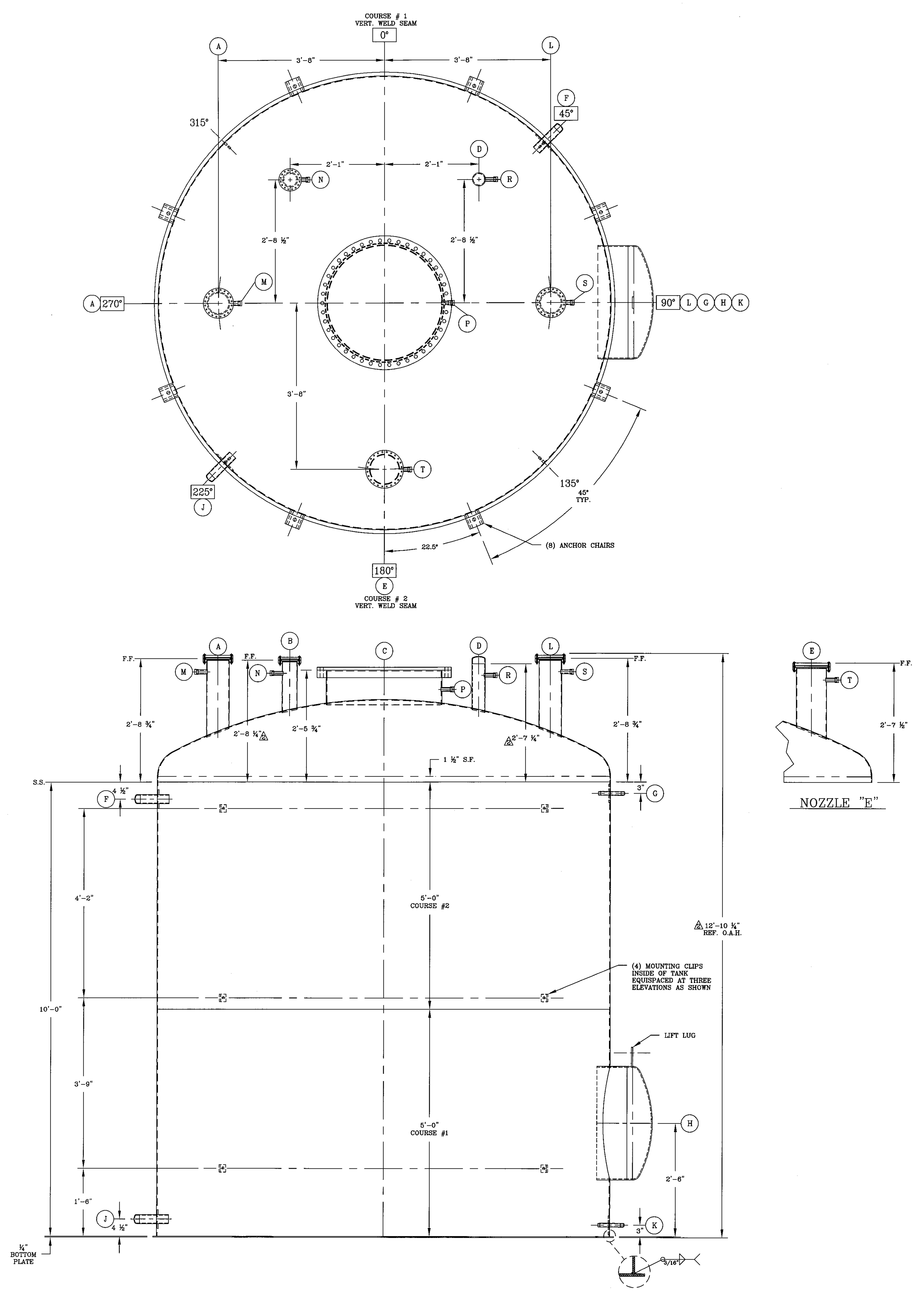
SOLUTION

Unit Settings: [F]/[psia]/[lbm]/[degrees]

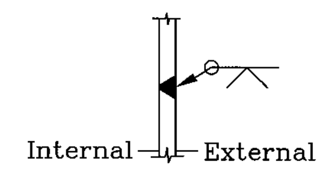
$A_{fill,Cu,ft2}$ = 0.0054 [ft^2]	$A_{fill,SS,ft2}$ = 0.006564 [ft^2]
$Cv_{cryolab}$ = 15.2	$Cv_{eden,globe}$ = 18
$Cv_{eden,Y}$ = 27	$\Delta P_{fill,psid}$ = 86.39 [psi]
$\Delta P_{tank,fill,line}$ = 86.39 [psi]	$dsmall_{fill,Cu}$ = 0.995 [ft]
$dsmall_{fill,SS}$ = 1.097 [in]	$D_{fill,Cu,ft}$ = 0.08292 [ft]
$D_{fill,SS,ft}$ = 0.09142 [ft]	$elevation_{head,\psi}$ = 15.83 [psi]
ε = 0.00015 [ft]	$f_{ci,fill,Cu}$ = 0.02304
$f_{ci,fill,SS}$ = 0.02251	$f_{T,fill,Cu}$ = 0.02281
$f_{T,fill,SS}$ = 0.02224	g = 32.17 [ft/s^2]
$GPM_{equivalent}$ = 33.76 [gal / min]	$K410_{fill,Cu}$ = 44.38 [ ]
$K410_{fill,SS}$ = 16.44	$K410_{SS,to,Cu}$ = 11.13 [ ]
$K_{elbow,fill,Cu}$ = 0.4562	$K_{elbow,fill,SS}$ = 0.4447
$K_{fill,Cu,pipe}$ = 20.52 [ ]	$K_{fill,SS,pipe}$ = 10.22 [ ]
$K_{pipe,exit}$ = 1	$K_{valve,cryolab}$ = 3.777 [ ]
$K_{valve,eden,globe}$ = 2.693 [ ]	$K_{valve,eden,Y}$ = 1.197 [ ]
$L_{eq,fill,Cu,ft}$ = 159.7 [ft]	$L_{fill,Cu,ft}$ = 73.83 [ft]
$L_{fill,SS,ft}$ = 41.5 [ft]	M = 39.95
μ = 0.1734 [cp]	M_{air} = 29
$num_{elbows,fill,Cu}$ = 3	$num_{elbows,fill,SS}$ = 14
P1p = 104.1 [psia]	P2p = 17.7 [psia]
$P_{average}$ = 60.9 [psia]	$q_{air,SCFH}$ = 262616 [SCFH]
$q_{air,SCFM}$ = 4377 [SCFM]	$Re_{fill,Cu}$ = 861337
$Re_{fill,SS}$ = 781249	$Re_{f,T,fill,Cu}$ = 1.000E+08
$Re_{f,T,fill,SS}$ = 1.000E+08	ρ_{fill} = 81.4 [lb$_m$/ft^3]
T_{air} = 519.7 [R]	T_i = 519.7 [R]
$Vbar1_{fill,ft3,lb}$ = 0.01286 [ft^3/lb$_m$]	$velocity_{ft,sec}$ = 14.89 [ft/sec]
WCAP = 23556 [lb/hr]	W_{fl} = 23556 [lb/hr]
$w_{lb,sec}$ = 6.543 [lb/sec]	x = 379.5

13 potential unit problems were detected.

VI. Tank Drawings



WELD PROCESS MAP



TYPICAL SHELL/SHELL
HEAD/SHELL WELDMENT

NOZZLE SCHEDULE

MK	SIZE	WEIGHT	FLG. TYPE	FLG. MAT'L	NOZZ. MAT'L	WALL	REPAD	SERVICE
A	8"	—	CONFLAT	T-304 SS	SA-511 304 SS	.120"		FEED THRU PORT
B	6"	—	CONFLAT	T-304 SS	SA-511 304 SS	.120"		RELIEF VALVE PORT
C	30"	—	PLATE	SA-240 304 SS	SA-240 304 SS	7 GA.		ACCESS PORT (MANWAY)
D	3"	—	CAP / PIPE	—	SA-312 304 SS	SCH 40		VENT
E	10"	—	CONFLAT	T-304 SS	SA-511 304 SS	.125"		HEAT EXCHANGER PORT
F	2"	—	CAP / PIPE	—	SA-312 304 SS	SCH 40	1/4" X 6" OD	PUMP RETURN
G	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40	1/4" X 6" OD	TANK PURGE
H	30"	—	DISHED	SA-240 304 SS	SA-240 304 SS	7 GA.		ACCESS PORT (MANWAY)
J	2"	—	CAP / PIPE	—	SA-312 304 SS	SCH 40	1/4" X 6" OD	PUMP & DRAIN
K	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40	1/4" X 6" OD	PURGE & DRAIN
L	8"	—	CONFLAT	T-304 SS	SA-511 304 SS	.120"		FEED THRU PORT
M	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40		TANK PURGE
N	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40		TANK PURGE
P	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40		TANK PURGE
R	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40		TANK PURGE
S	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40		TANK PURGE
T	3/4"	—	CAP/THR'D PIPE	—	SA-312 304 SS	SCH 40		TANK PURGE

DESIGN CONDITIONS

	Vessel Int.	Vessel Ext.	Jacket/Channel/H.O.C. Int.	Jacket/Channel/H.O.C. Ext.	Coil
Design Pressure	3.0 PSI	0.2 PSI	—	—	—
Design Temp.	-320° / 100°F	-320° / 100°F	-na° / na°F	-na° / na°F	—
Operating Press.	—	—	—	—	—
Operating Temp.	—	—	—	—	—
Corrosion Allow.	—		—		—
Specific Gravity	1.4		Liquid Level 10'-0"		
Static Pressure	Bott. Head 6.062		Bott. T.L. na		

Heads	Type	D.R.	I.C.R.	S.F.
Left / Top	ASME F&D	120"	7.2"	1.5"
Right / Bot.	FLAT	—	—	—
Jacket	—	—	—	—
Channel	—	—	—	—

X-Ray	None	Spot	Full
Vessel	—	—	X
Jacket	—	—	—
Channel	—	—	—

Joint Efficiency	Lf/Tp Hd	Rt/Bt Hd	Shell
Vessel	70%	70%	70%
Jacket	—	—	—
Channel	—	—	—

Hydro @ Amb. Temp.	Vessel —	Jacket/H.O.C.	—
	Channel —	Coil	—
PWHT	—	Wind Load	—
Earthquake	ZONE 1	Lethal Service	—
Code	API na		
	ASME na		

MATERIAL

Shell	SA-240 304 SS Thk. 7 GA.	Channel Shell	— Thk. —
Left /Top Hd.	SA-240 304 SS	Min. Thk.	(7 GA. NOM.)
Right/ Bott. Hd.	SA-240 304 SS	Min. Thk.	(7 GA. NOM.)
Jakt. Shell	— Thk. —	Jakt. Hd.	— Min. Thk. —
H.O.C.	— Shell —	Ga Thk.	—
H.O.C.	— Head —	Ga Thk.	—

Tubes	Dia.	Thk.	Qty.	Pitch	Mat'l
	—	—	—	—	—

Tube Sheet	— Thk. —	Exp. Jt.	— Thk. —
Channel Flg	— Thk. —	w/	— Thk. Liner
C.STL. Flg. w/	—	overlays/liner	— Thk.
Flanges	T-304 SS	Pipes	SA-312/511 304 SS
Stub Ends	—	Coil	— Thk. —
Couplings	—	Gaskets	COPPER/INDIUM WIRE
Bolts	T-304 SS	Nuts	T-304 SS
Baffles	—	Repads	SA-240 304 SS
Ins./Stiff. Rings	—	Lift Lugs	SA-240 304 SS
Supports	SA-240 304 SS	Supp. Clips	SA-240 304 SS
Manhole YES	Hinged NO	Davit NO	No support

WELD SPECIFICATIONS

Shell/Head	WPS # 02 & 28	Shell/Shell	WPS # 02 & 28
Flange/Pipe	WPS # 02 & 28	Pipe/Shell or Head	WPS # 02 & 28
Pipe/Pipe	WPS # 02 & 28	C.S./Stainless	WPS # 03

SURFACE PREPARATION

Internal		External	
Surface Prep	—	Surface Prep	—
Primer	—	Primer	—
Fin. Coat	—	Fin. Coat	—
Polish/Lining	—		

GENERAL INFORMATION

Capacity		6,506 Gallons
Weight	Empty	0,000 Lbs.
	Full of Water	Gal. x 8.345 Lbs.
	Operation @ N.L.L.	Lbs. @ 1.0 S.G.
H.O.C.	Hd. L.F.	Shell L.F.
NATIONAL BOARD NO.		

GENERAL NOTES

1. Lifting Lugs designed for empty vessel weight ONLY.

2.

3.

4.

5.

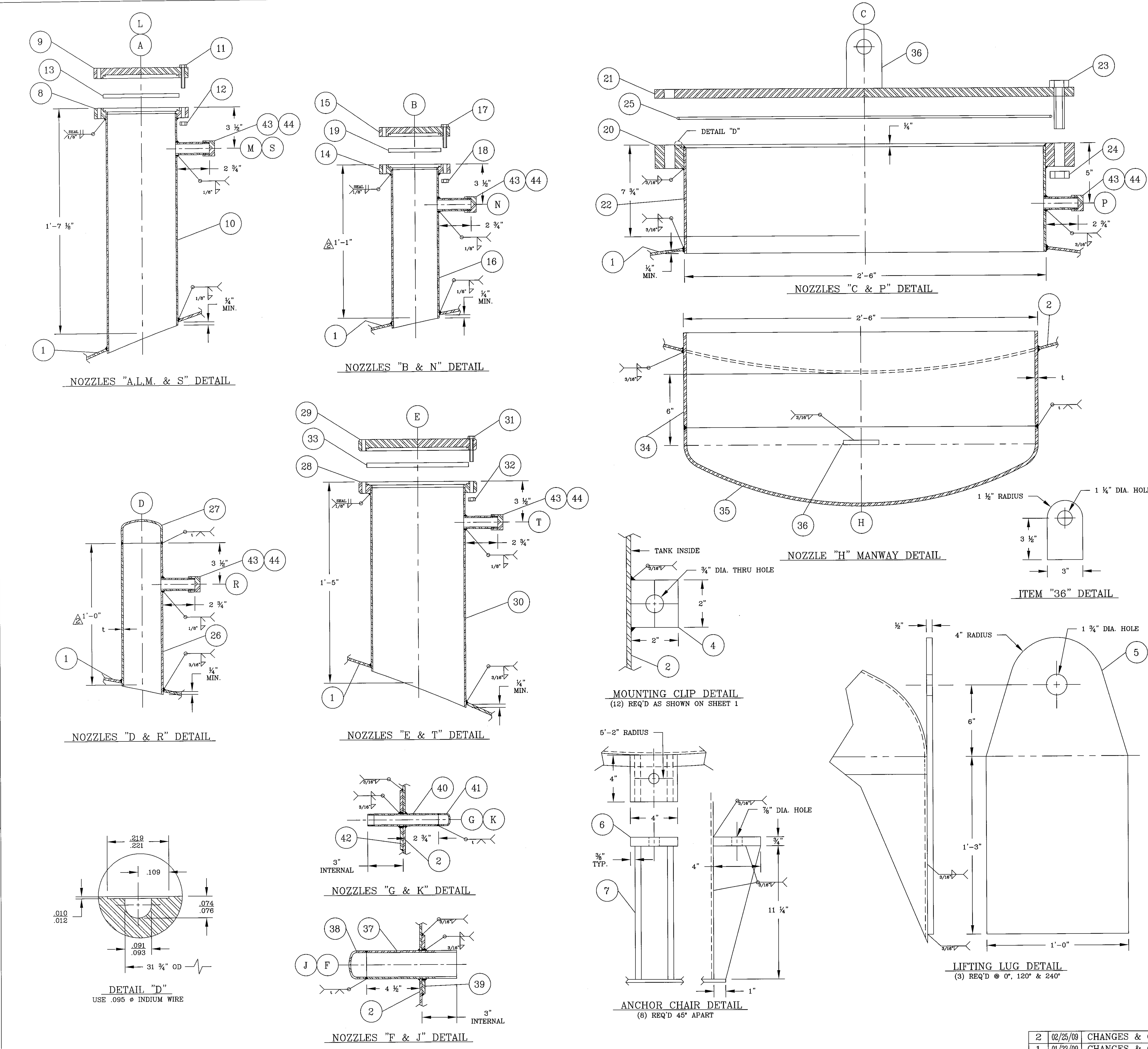
RELEASED
FOR FABRICATION
CHIEF ENGR. Acw
DATE: 3/18/09

1. After final hydrostatic test, the vessel shall be cleaned thoroughly on the inside and outside. Remove all weld slag, spatter, loose scale, rust dirt and grease.
2. All flanged openings, not provided with blind flanges shall be protected with plastic flange covers, where suitable. Threaded openings shall be plugged with a plastic or metal cap.
3. For internal parts suitable supports shall be provided to avoid damage during shipment or the parts will be shipped loose for field installation.
4. Small parts which are to be shipped loose, shall be bagged or boxed and marked with the customer order number and item number of the vessel.
5. Flange bolt holes to straddle principal center line of the vessel.
6. Drill and tap 1/4" dia. weep hole on all reinforcing pads. If a split repad is used drill and tap 1/4" dia. weep holes in each portion of the repad.
7. All nozzles to have minimum interior projection unless otherwise specified. All nozzles to have 6" min. exterior projection unless otherwise specified.
8. All nozzles on flat roof tanks can not be guaranteed to be level due to distortion caused by welding and handling.
9. All spin hole in formed heads that do not utilized for a nozzle will be weld repaired & that weld will be die penrtrant checked internally & externally after welding.

REV	DATE	DESCRIPTION
2	02/25/09	CHANGES & CORRECTIONS PER CUSTOMER REQUEST.
1	01/23/09	CHANGES & CORRECTIONS PER CUSTOMER REQUEST.

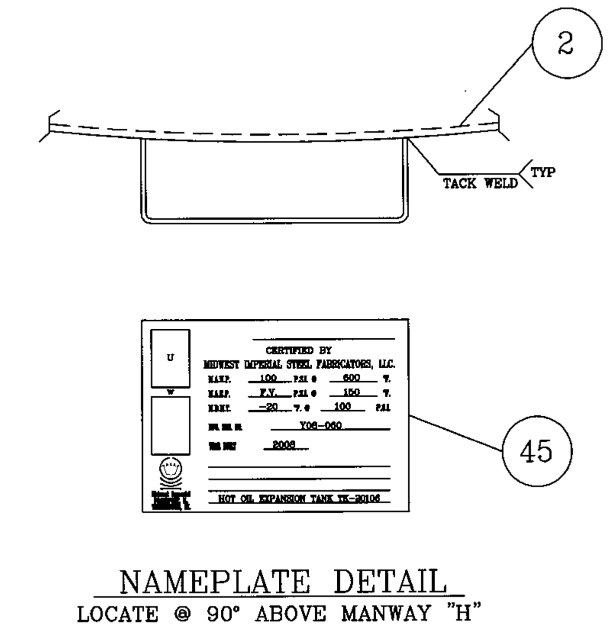
MIDWEST IMPERIAL STEEL FABRICATORS, LLC.
400 South LaGrange Road, Frankfort, Illinois 60423

SCALE:	APPROVED BY:	DRAWN BY: J. Rodriguez
DATE: 12/29/08		REVISED: J. Rodriguez
(1) 10'-0" OD X 10'-0" STRAIGHT SHELL LIQUID ARGON TANK		Job No. Y08-125
CUSTOMER FERMI NATIONAL LABORATORY BATAVIA, ILLINOIS	CUSTOMER P.O. 583306	DRAWING-SHT. Y08-125-1 REV. 2



BILL OF MATERIAL

ITEM	QTY.	DESCRIPTION	MATERIAL	WEIGHT	SUPPLIER
1	1	HEAD, 120" OD ASME F&D	SA-240 304/304L SS	738	TBD
2	2	SHELL, SHEET 7 GA. X 60" X 377"	SA-240 304/304L SS	2,473	TBD
3	2	BOTTOM, SHEET 7 GA. X 121" RADIUS HALF CIRCLE	SA-240 304/304L SS	820	TBD
4	12	MOUNTING CLIPS, PLATE 1/2" X 2" X 2"	SA-240 304/304L SS	8	TBD
5	3	LIFT LUGS, PLATE 3/8" X 12" X 25"	SA-240 304/304L SS	87	TBD
6	8	ANCHOR CHAIR TOP PLATE, 3/4" X 4" X 4"	SA-240 304 SS	29	TBD
7	16	ANCHOR CHAIR GUSSET PLATE, 1/2" X 4" X 11 1/4"	SA-240 304 SS	108	TBD
		NOZZLES "A & L"			
8	2	FLANGE, 8" CONFLAT SKT WELD	T-304/304L SS	24	TBD
9	2	FLANGE, 8" CONFLAT BLIND	T-304/304L SS	30	TBD
10	1	TUBE, 6" OD X 0.120" WALL X 4'-0"	T-304/304L SS	30	TBD
11	16	HEX BOLT, 5/16"-24UNC X 0'-3 1/2" LG.	SA-193 B7	2	TBD
12	16	HEX NUT, 5/16"-24UNC	SA-194 2H	1	TBD
13	2	GASKET, 8" CONFLAT LDS	COPPER	1	TBD
		NOZZLE "B"			
14	1	FLANGE, 6" CONFLAT SKT WELD	T-304/304L SS	9	TBD
15	1	FLANGE, 6" CONFLAT BLIND	T-304/304L SS	9	TBD
16	1	TUBE, 4" OD X 0.120" WALL X 2'-0"	T-304/304L SS	10	TBD
17	8	HEX BOLT, 5/16"-24UNC X 0'-2 1/2" LG.	SA-193 B7	2	TBD
18	8	HEX NUT, 5/16"-24UNC	SA-194 2H	1	TBD
19	1	GASKET, 6" CONFLAT LDS	COPPER	1	TBD
		NOZZLE "C" MANWAY			
20	1	PLATE RING, 2" X 30 1/4" ID X 35 1/2" OD	SA-240 304/304L SS	160	TBD
		WITH (42) 7/8" DIA. HOLES ON 33" B.C.			
		AND O-RING GROOVE PER DETAIL "D"			
21	1	PLATE CIRCLE, 3/4" X 35 1/2" OD	SA-240 304/304L SS	210	TBD
		WITH (42) 7/8" DIA. HOLES ON 33" B.C.			
		AND GASKET SURFACE ONE SIDE			
22	1	SHEET, 7 GA. X 8" X 97"	SA-240 304/304L SS	43	TBD
23	42	HEX BOLT, 3/4"-10UNC X 0'-4" LG.	SA-193 B7	10	TBD
24	42	HEX NUT, 3/4"-10UNC	SA-194 2H	5	TBD
25	1	GASKET, 0.1875" X 31 3/4" OD	INDIUM WIRE	2	TBD
		NOZZLE "D"			
26	1	PIPE, 3"-SCH 40 X 2'-0" B.O.E.	SA-312 304/304L SS	15	TBD
27	1	WELD CAP, 3"-SCH 40	SA-403 304/304L SS	4	TBD
		NOZZLE "E"			
28	1	FLANGE, 10" CONFLAT SKT WELD	T-304/304L SS	18	TBD
29	1	FLANGE, 10" CONFLAT BLIND	T-304/304L SS	26	TBD
30	1	TUBE, 8" OD X 0.120" WALL X 1'-8"	T-304/304L SS	23	TBD
31	20	HEX BOLT, 5/16"-24UNC X 0'-2 1/2" LG.	SA-193 B7	2	TBD
32	20	HEX NUT, 5/16"-24UNC	SA-194 2H	1	TBD
33	1	GASKET, 10" CONFLAT LDS	COPPER	1	TBD
		NOZZLE "H" MANWAY			
34	1	SHEET, 7 GA. X 12" X 97"	SA-240 304/304L SS	64	TBD
35	1	HEAD, 30" OD ASME F&D	SA-240 304/304L SS	50	TBD
36	2	LIFT LUG, PLATE 3/8" X 3" X 5"	SA-240 304/304L SS	8	TBD
		NOZZLE "F & J"			
37	1	PIPE, 2"-SCH 40 X 1'-8" B.B.E.	SA-312 304/304L SS	6	TBD
38	1	WELD CAP, 2"-SCH 40	SA-403 304/304L SS	6	TBD
39	1	REPAD, PLATE 1/4" X 2 5/8" ID X 6" OD	SA-240 304/304L SS	3	TBD
		NOZZLE "G & K"			
40	1	PIPE, 3/4"-SCH 40 X 1'-8" T.B.E.	SA-312 304/304L SS	2	TBD
41	1	WELD CAP, 3/4"-SCH 40	SA-403 304/304L SS	2	TBD
42	1	REPAD, PLATE 1/4" X 1 1/4" ID X 6" OD	SA-240 304/304L SS	2	TBD
		NOZZLE "G & K"			
43	3	PIPE NIPPLE, 3/4"-SCH 40 X 0'-8"	SA-312 304/304L SS	3	TBD
44	6	PIPE CAP, 3/4"-SCH 40 THREADED	SA-403 304/304L SS	4	TBD
45	1	NAMPLATE	S.S.	1	MIDWEST IMPERIAL



GENERAL NOTES

1. Lifting Lugs designed for empty vessel weight ONLY.
2.
3.
4.
5.

RELEASED
FOR FABRICATION
CHIEF ENGR.
DATE: 3/18/09

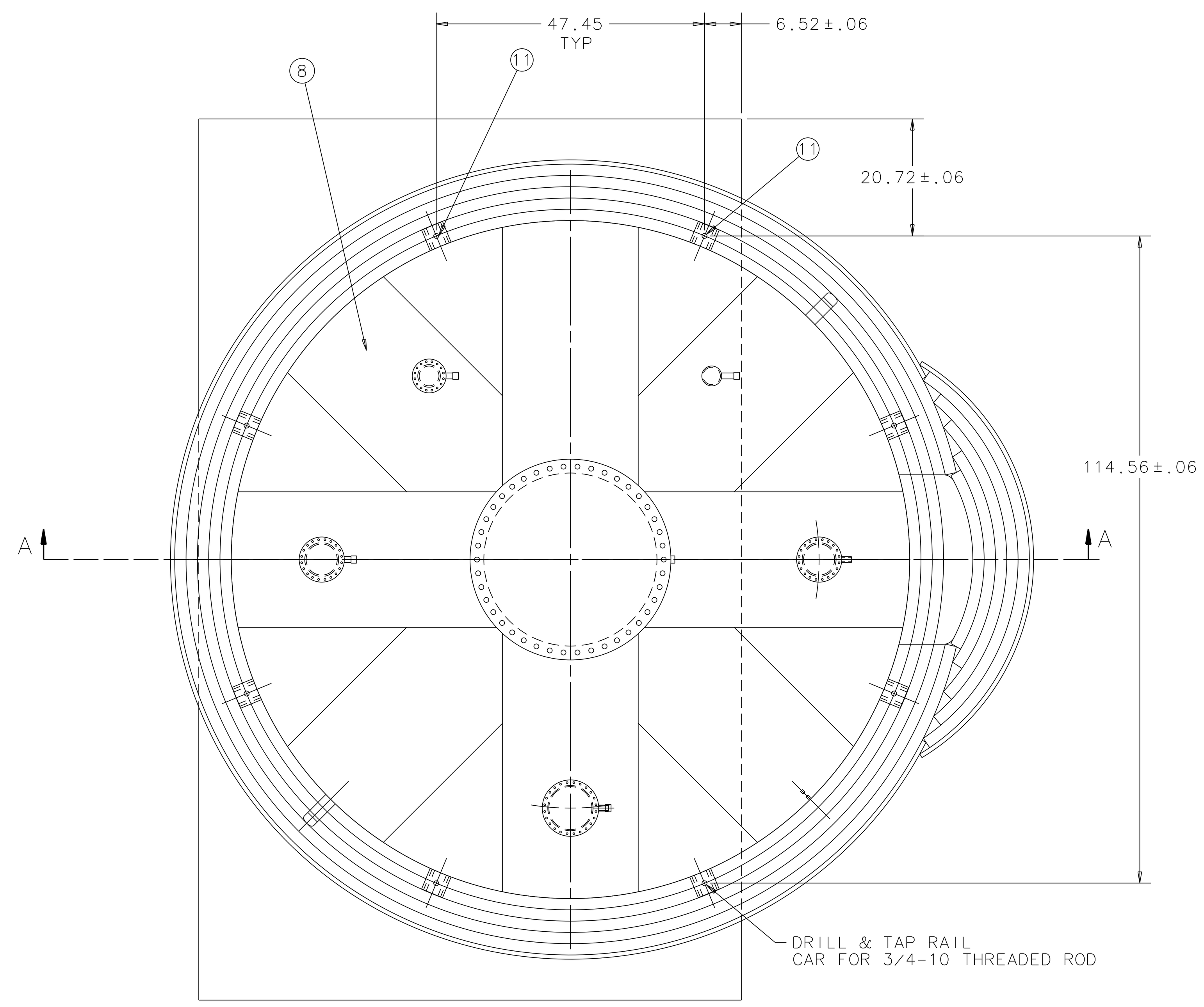
REV	DATE	DESCRIPTION
2	02/25/09	CHANGES & CORRECTIONS PER CUSTOMER REQUEST.
1	01/23/09	CHANGES & CORRECTIONS PER CUSTOMER REQUEST.
0	12/29/08	SENT OUT FOR APPROVAL.

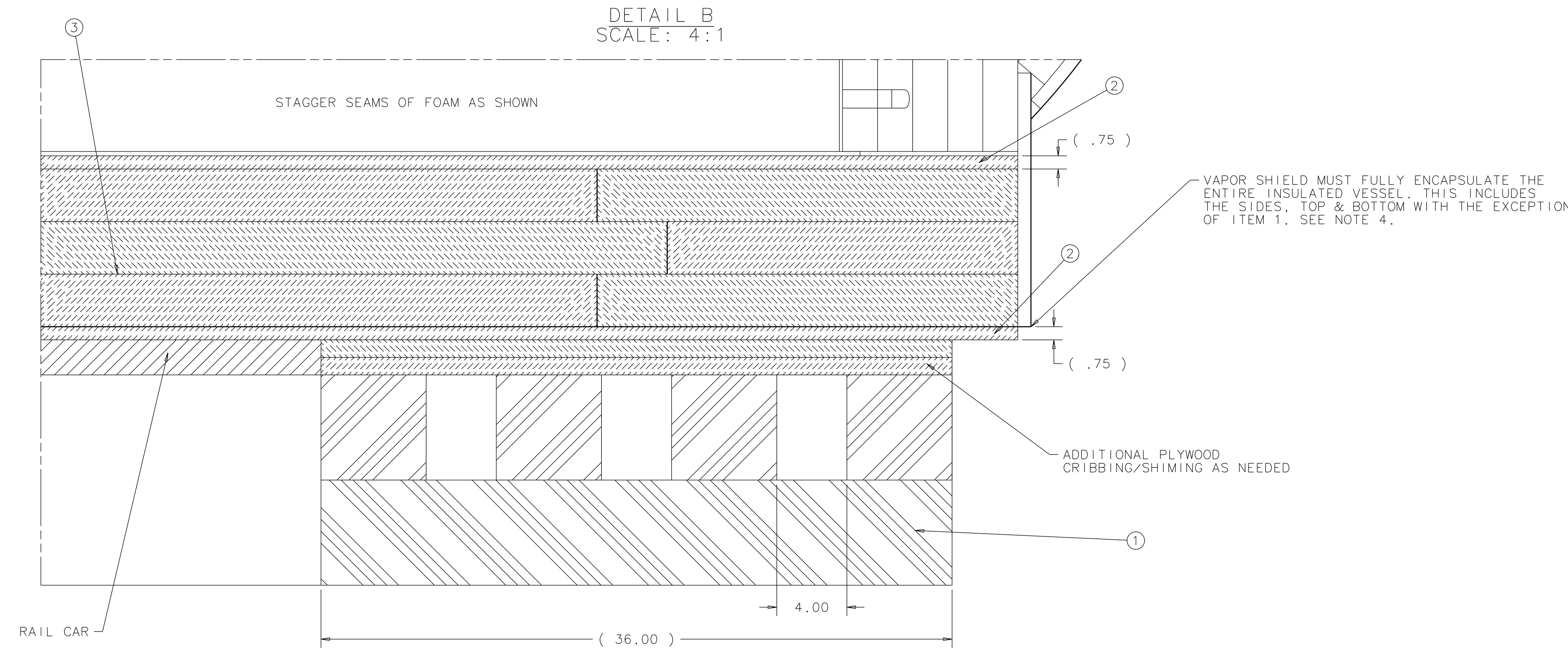
MIDWEST IMPERIAL STEEL FABRICATORS, LLC.
400 South LaGrange Road Frankfort, Illinois 60423

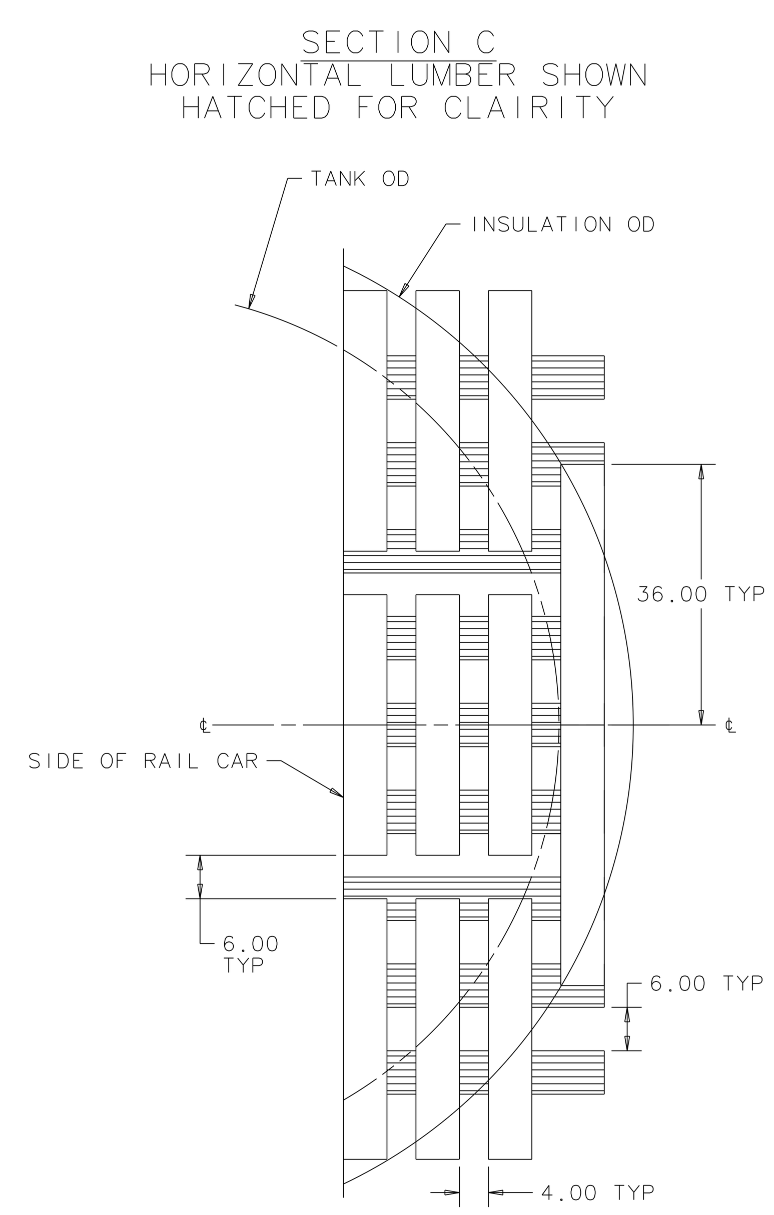
SCALE:
DATE: 12/29/08
APPROVED BY:
DRAWN BY: J. Rodriguez
REVISED: J. Rodriguez
(1) 10'-0" OD X 10'-0" STRAIGHT SHELL LIQUID ARGON TANK
Job No. Y08-125
CUSTOMER FERMI NATIONAL LABORATORY BATAVIA, ILLINOIS
CUSTOMER P.O. 583306
DRAWING-SHT. Y08-125-2
REV. 2

1. After final hydrostatic test, the vessel shall be cleaned thoroughly on the inside and outside. Remove all weld slag, spatter, loose scale, rust dirt and grease.
2. All flanged openings, not provided with blind flanges shall be protected with plastic flange covers, where suitable. Threaded openings shall be plugged with a plastic or metal cap.
3. For internal parts suitable supports shall be provided to avoid damage during shipment or the parts will be shipped loose for field installation.
4. Small parts which are to be shipped loose, shall be bagged or boxed and marked with the customer order number and item number of the vessel.
5. Flange bolt holes to straddle principal center line of the vessel.
6. Drill and tap 1/4" dia. weep hole on all reinforcing pads. If a split repad is used drill and tap 1/4" dia. weep holes in each portion of the repad.
7. All nozzles to have minimum interior projection unless otherwise specified. All nozzles to have 6" min. exterior projection unless otherwise specified.
8. All nozzles on flat roof tanks can not be guaranteed to be level due to distortion caused by welding and handling.
9. All spin hole in formed heads that do not utilized for a nozzle will be weld repaired & that weld will be die penrtrant checked internally & externally after welding.

REV	DESCRIPTION	DRAWN / APPROVED	DATE
A	REMOVED NOTE 2.3.1 ; REVISED PARTS LIST ; CHANGED LAYOUT TO SUIT 24" X 48" PANELS	J.MATESKI	15-JUL-2009

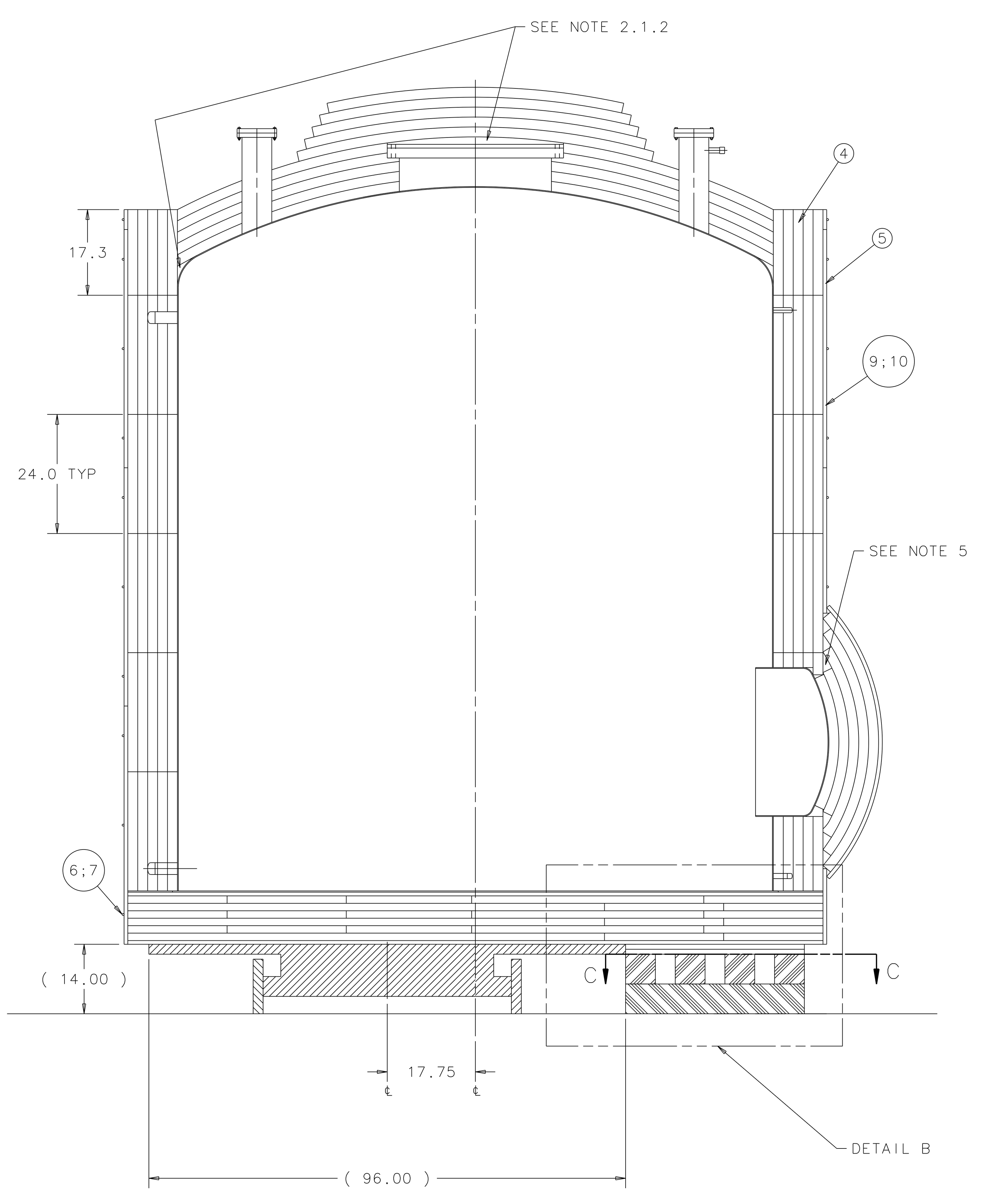






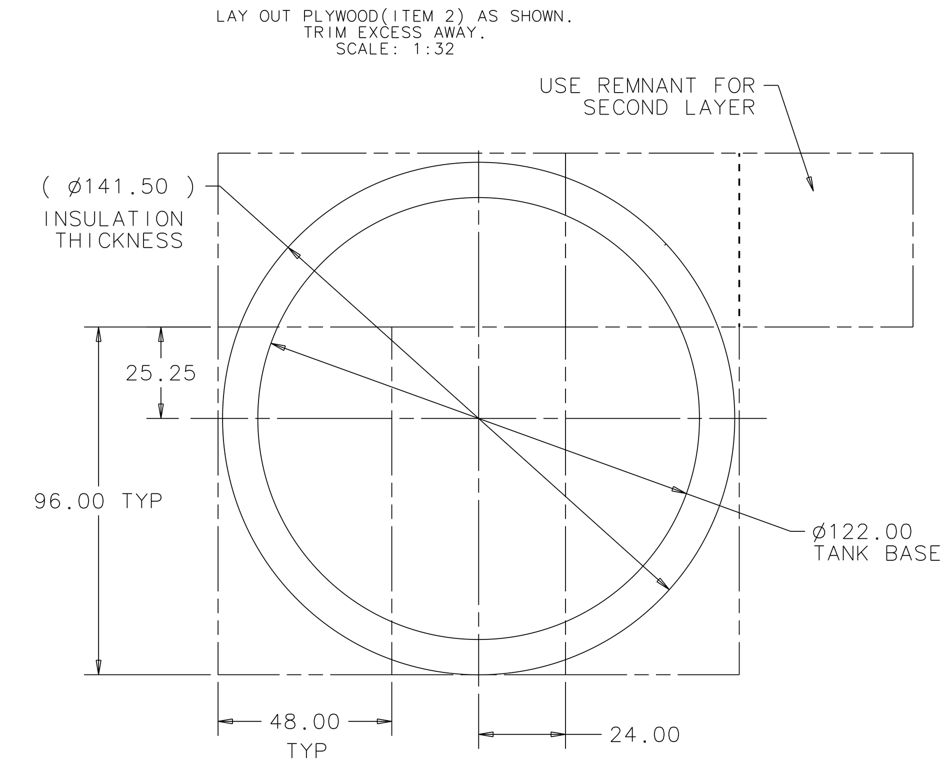
INSULATION NOTES:

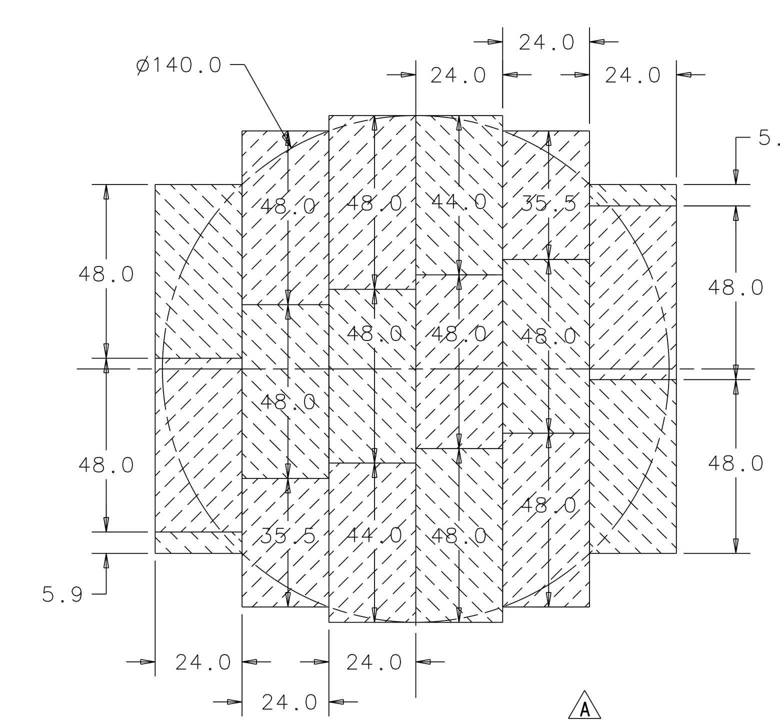
1. FLOOR:
 1.1. INSTALL 4 THREADED RODS (ITEM 11) IN RAIL CARS.
 1.2. LAYOUT LOWER PLYWOOD ON CARS AS SHOWN.
  1.2.1. SHIM AS NECESSARY SO PLYWOOD IS LEVEL ± 0.125
 1.3. COVER PLYWOOD WITH 2 COATS OF MASTIC (ITEM 10). SEAL HOLES WHERE THREADED RODS PROTRUDE.
 1.4. LAYOUT FOAM BOARDS AS SHOWN
  1.4.1. STAGGER ALL SEAMS.
  1.4.2. ALTERNATE DIRECTION WITH EACH LAYER.
  1.4.3. SEAM SEAMS WITH MASTIC
  1.4.4. FILL GAPS WITH "GREAT STUFF" EXPANDING FOAM
 1.5. LAYOUT TOP PLYWOOD.
 1.6. LOWER TANK ON TO RAIL CARS
 1.7. ANCHOR TO RAIL CARS WITH THREADED ROD.
 1.8. ROLL VESSEL INTO HALL
 1.9. PLACE CRIBBING AROUND TANK BOTTOM TO FULL INSULATION DIAMETER.
 1.10. INSTALL REMAINING ANCHOR BOLTS
2. VESSEL SIDES:
 2.1. COVER SIDES WITH 5 LAYERS OF ITEM 4. STAGGER ALL VERTICAL SEAMS.
  2.1.1. FIT INSULATION SNUGLY OVER & AROUND ALL FEATURES & PROTRUSIONS OF VESSEL. ALL SURFACES OF VESSEL MUST BE INSULATED TO A DEPTH OF 10".
  2.1.2. FILL VOIDS IN ITEM 4 WITH ITEM 8
 2.2. APPLY 1 COMPLETE LAYER OF ITEM 5 TO THE INSULATED VERTICAL WALLS.
 2.3. SECURE INSULATION TO VESSEL USING AT LEAST 3 COMPLETE WRAPS OF ITEM 6. ENSURE THAT STRAP IS LEVEL & TIGHT.
  2.3.2. FILL VOIDS IN ITEM 5 WITH "GREAT STUFF" EXPANDING FOAM
 2.4. SEAL SEAMS BETWEEN BOARDS WITH MASTIC
 2.5. FILL VOIDS & CRACKS IN ITEM 5 WITH "GREAT STUFF" EXPANDING FOAM
3. VESSEL ROOF:
 3.1. COVER ROOF WITH 5 LAYERS OF ITEM 8
  3.1.1. FIT INSULATION SNUGLY OVER & AROUND ALL FEATURES & PROTRUSIONS OF VESSEL. ALL SURFACES OF VESSEL MUST INSULATED TO A DEPTH OF 10".
  3.1.2. FILL ALL VOIDS, GAPS & AIR POCKETS IN INSULATION WITH ITEM 8
 3.2. APPLY 1 LAYER OF ITEM 5 TO THE INSULATED ROOF.
  3.2.1. FILL VOIDS & GAPS IN ITEM 5 WITH "GREAT STUFF" EXPANDING FOAM
4. VAPOR SHIELD:
 VAPOR SHIELD MUST FULLY ENCAPSULATE THE ENTIRE INSULATED VESSEL. THIS INCLUDES THE SIDES, TOP & BOTTOM.
 4.1. ENCAPSULATE THE ENTIRE INSULATED VESSEL WITH MASTIC & REINFORCING MESH
  4.1.1. APPLY 2 COATS PER MANUFACTURES RECOMMENDED PROCEDURES.



SECTION A-A

LAY OUT PLYWOOD(ITEM 2) AS SHOWN.
TRIM EXCESS AWAY.
SCALE: 1:32





LAY OUT BASE INSULATION (ITEM 3)
AS SHOWN SO NO SEAMS LINE UP.
LAY ADDITIONAL LAYERS PERPENDICULAR
TRIM EXCESS AWAY.
SCALE: 1:32

ITEM	PART NO.	DESCRIPTION OR SIZE	QTY.
14	ON HAND	GREAT STUFF EXPANDING FOAM INSULATION	
13			
12	1210-080000	3/4-10 SS HEX NUT	8
11	COML	3/4-10 x 36" SS THREADED ROD, McMASTER-CARR #98847A036, ALSO #98920A036 3/4-10 X 72" LG. FOR USE OFF OF THE CAR.	4
10	COML	FOSTER 30-90 VAPOR SAFE MASTIC 5 GAL CONTAINER	8
9	COML	GLASS CLOTH ROLLS 3 FT. W. X 150 FT. LG. WHITE GL 1659	600 SQ FT
8	COML	2 X 24 X 48 FIBERGLASS INS OWENS CORNING: 701	200
7	COML	ALETAL NO-SEW BUCKLE MCMASTER CARR: #29705T22	1 PK
6	COML	1" NYLON WEBBING MCMASTER CARR: #3510T12	600'
5	COML	0.75 X 48 X 96 TRYMER 2000 XP ITW INSULATION	14
4	COML	2 X 24 X 48 FIBERGLASS INS OWENS CORNING: 702	275
3	COML	3 X 24 X 48 TRYMER 3000 XP ITW INSULATION	55
2	1850-260000	3/4" X 48" X 96" PLYWOOD SHEET	9
1	1850-160000	PLASTIC LUMBER, 6 X 6 X 36 LG	20

PARTS LIST

UNLESS OTHERWISE SPECIFIED					
FRACTIONS ± 1/4	DECIMAL ± - -	ANGLES ± - -	ORIGINATOR	R.SCHMITT	22-FEB-2009
			DRAWN	J.TILLMAN	01-APR-2009
			CHECKED	J.RAUCH	10-JUN-2009
			APPROVED	R.SCHMITT	10-JUN-2009

1. BREAK ALL SHARP EDGES - - MAX.
2. DO NOT SCALE DRAWING.
3. DIMENSIONS BASED UPON ASME Y14.5M-1994
4. MAX. ALL MACH. SURFACES - -
5. DRAWING UNITS: U.S. INCH

USED ON

MATERIAL: SEE PARTS LIST ABOVE

FERMI NATIONAL ACCELERATOR LABORATORY
UNITED STATES DEPARTMENT OF ENERGY

FLARE - GENERAL PRELIMINARY DESIGN LAR TANK INSULATION

SCALE	DRAWING NUMBER	SHEET	REV
1:16 & NOTED	3942.000-ME-466366	1 OF 1	A

CREATED WITH : Ideas12NXSeries | GROUP: PPD/MECHANICAL DEPARTMENT

VII. FABRICATION

A. Material Certificates

B. Welding Procedures

C. Name Plate Photograph

D. API Compliance Certificate

#6

THAI - GERMAN PRODUCTS PUBLIC CO., LTD
MILL TEST CERTIFICATE TO EN 10204/3.1B

ISSUED DATE : 4/7/2008
S/N NO. : 2008/015 ORDER 2
MESSRS. : NORCA INDUSTRIAL COMPANY LLC
L/C NO. :

INVOICE NO. : TGP2008/121
CUSTOMER'S REF. NO. : 525/001357

STANDARD SPECIFICATION : ASTM A 312 / A 312M - 01A — GRADE TP 304/304L

CRATE NO.	DIMENSION OD. X Thick X Length UNIT :INCH	QTY (Pcs.)	WEIGHT (Kgs.)	HEAT/ PRODUCTION NO.	CHEMICAL COMPOSITION (%) C	Si	Mn	P	S	Ni	Cr	Mo	Hardness (HRB)	Mechanical Properties YS (Ksi)	TS (Ksi)	EL %	Hydro - Static test AT 5 SEC.	Flat- tening	Width of specimen
					0.035 Max	1.00 Max	2.00 Max	0.045 Max	0.030 Max	8.00 - 11.00	18.00 - 20.00	- - - -	90 max	25 MIN.	70 MIN.	35 MIN.	MIN. (Psi)	(MM)	(MM)
10	11/2" X SCH10S X 20FT.	5	96.08	FM070306512	0.025	0.394	1.961	0.037	0.010	8.100	18.357	-	83	68	94	39	1800	19.1	19.0
10	11/2" X SCH10S X 20FT.	25	480.40	FM070306511	0.025	0.394	1.961	0.037	0.010	8.100	18.357	-	83	69	96	42	1800	19.1	19.0
10	3/4" X SCH40S X 20FT.	38	395.83	FM060306511	0.035	0.389	1.091	0.030	0.012	8.088	18.100	-	83	68	97	41	3300	15.1	12.7
10	3/4" X SCH40S X 20FT.	11	114.58	FM063005511	0.035	0.400	1.113	0.035	0.011	8.080	18.088	-	83	69	97	39	3300	15.1	12.7
10	3/4" X SCH40S X 20FT.	41	427.08	FM062905512	0.035	0.400	1.113	0.035	0.011	8.080	18.088	-	83	69	97	39	3300	15.1	12.7
10	3/4" X SCH40S X 20FT.	10	104.17	FM063005513	0.035	0.389	1.091	0.030	0.012	8.088	18.100	-	84	70	98	39	3300	15.1	12.7
10	3/4" X SCH40S X 20FT.	10	104.17	FM062805512	0.035	0.400	1.113	0.035	0.011	8.080	18.088	-	83	68	95	40	3300	15.1	12.7
16	3.0" X SCH10S X 20FT.	19	758.69	FM150506511	0.035	0.588	1.252	0.031	0.010	8.214	18.409	-	83	68	98	39	1100	24.7	25.4
16	11/4" X SCH10S X 20FT.	30	499.18	FM012702512	0.035	0.431	1.220	0.020	0.009	8.351	18.494	-	84	70	98	39	2000	18.2	19.0
22	4.0" X SCH40S X 20FT.	16	1590.50	FM160406511	0.035	0.435	1.064	0.027	0.007	8.040	18.270	-	85	71	100	38	1600	42.9	38.1

PROCESS : WELDED
FINISH : ANNEALED AND PICKLED
TESTING : FLATTENING

RESULT : PASS
RESULT :
RESULT :
RESULT :
RESULT :

HEAT TREATMENT : 1040 C WATER QUENCHING
SURFACE & DIMENSIONAL CONTROL BY VISUAL ACCORDING TOA 999 : GOOD

WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HERE IN HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH THE SPECIFICATION

DK
2-13-09

ASSURED BY : C. Ha-Ohon
QA DIVISION MANAGER

REMARK : MATERIAL FREE OF MERCURY CONTAMINATION NO WELD REPAIR

RF - QA - 011 2008/015/5

Rev. 2 : 09/50

MILL TEST REPORTS FURNISHED BY
MIDWEST SPECIALTY METALS, INC.
DATE 2-11-09 OUR ORDER NO. 10684
CUSTOMER Midwest/Imperial
YOUR P.O. Y08125-71221

#7

THAI - GERMAN PRODUCTS PUBLIC CO., LTD
MILL TEST CERTIFICATE TO EN 10204/3.1B

ISSUED DATE : 24/8/2008
S/N NO. : 2008/040 ORDER 2
MESSRS. : NORCA INDUSTRIAL COMPANY LLC
L/C NO. :

INVOICE NO. : TGP2008/178
CUSTOMER'S REF. NO. : 525/001375

STANDARD SPECIFICATION : ASTM A 312 / A 312M - 01A — GRADE TP 304/304L — CHEMICAL COMPOSITION (%)

CRATE NO.	DIMENSION OD. X Thick X Length UNIT :INCH	QTY (Pcs.)	WEIGHT (Kgs.)	HEAT/ PRODUCTION NO.	C 0.035 Max	SI 1.00 Max	Mn 2.00 Max	P 0.045 Max	S 0.030 Max	Ni 8.00 - 11.00	Cr 18.00 - 20.00	Mo -	Hardness (HRB) 90 max	Mechanical Properties YS (Ksi) 25 MIN.	TS (Ksi) 70 MIN.	EL % 35 MIN.	Hydro-Static test AT 5 SEC. MIN. (Psi)	Flat-tening (MM)	Width of specimen (MM)
6	1/2" X SCH40S X 20FT.	8	62.76	FM243005511	0.025	0.322	1.964	0.034	0.010	8.159	18.159	-	83	66	96	40	3900	13.1	12.7
6	1/2" X SCH40S X 20FT.	3	23.53	FM243005513	0.023	0.388	1.986	0.034	0.009	8.198	18.500	-	83	66	96	40	3900	13.1	12.7
6	1/2" X SCH40S X 20FT.	2	15.69	FM243005515	0.022	0.367	1.954	0.030	0.011	8.138	18.122	-	83	66	94	41	3900	13.1	12.7
17	2.0" X SCH40S X 20FT.	38	1278.39	FM050408513	0.035	0.456	1.339	0.024	0.008	8.082	18.241	-	82	67	94	40	2000	27.5	25.4
17	2.0" X SCH40S X 20FT.	22	740.12	FM052807515	0.021	0.318	1.764	0.025	0.009	8.109	18.135	-	83	69	98	38	2000	27.5	25.4
* 18	2.0" X SCH40S X 20FT.	9	302.78	FM052807515	0.021	0.318	1.764	0.025	0.009	8.109	18.135	-	83	69	98	38	2000	27.5	25.4
18	2.0" X SCH40S X 20FT.	37	1244.75	FM050408512	0.035	0.455	1.329	0.024	0.008	8.098	18.222	-	83	67	93	38	2000	27.5	25.4
18	2.0" X SCH40S X 20FT.	3	100.93	FM052307513	0.028	0.398	1.879	0.032	0.010	8.098	18.115	-	84	71	99	39	2000	27.5	25.4
18	2.0" X SCH40S X 20FT.	11	370.06	FM050108511	0.035	0.370	1.115	0.022	0.011	8.088	18.387	-	84	68	94	38	2000	27.5	25.4
19	2.0" X SCH40S X 20FT.	22	740.12	FM052307513	0.023	0.398	1.879	0.032	0.010	8.098	18.115	-	84	71	99	39	2000	27.5	25.4

PROCESS : WELDED
FINISH : ANNEALED AND PICKLED
TESTING : FLATTENING

RESULT : PASS
RESULT :
RESULT :
RESULT :
RESULT :

HEAT TREATMENT : 1040 C WATER QUENCHING
SURFACE & DIMENSIONAL CONTROL BY VISUAL ACCORDING TOA 999 : GOOD

WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HERE IN HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH THE SPECIFICATION

2-13-09

ASSURED BY : C. [signature]
QA DIVISION MANAGER

REMARK : MATERIAL FREE OF MERCURY CONTAMINATION NO WELD REPAIR

RF - QA - 011 2008/040/9

Rev. 1 : 12/43

MILL TEST REPORTS FURNISHED BY
MIDWEST SPECIALTY METALS, INC.
DATE 2-11-09 OUR ORDER NO. 10684
CUSTOMER MIDWEST IMPERIAL
YOUR P.O. Y08125-41321

#8

THAI - GERMAN PRODUCTS PUBLIC CO., LTD

MILL TEST CERTIFICATE TO EN 10204/3.1B

ISSUED DATE : 27/6/2008
S/N NO. : 2008/029 ORDER 2
MESSRS. :
L/C NO. :

INVOICE NO. : TGP2008/112
CUSTOMER'S REF. NO. : 525/001367

STANDARD SPECIFICATION : ASTM A 312 / A 312M - 01A — GRADE TP 304/304L

CRATE NO.	DIMENSION OD. X Thick X Length UNIT :INCH	QTY (Pcs.)	WEIGHT (Kgs.)	HEAT/ PRODUCTION NO.	C 0.035 Max	Si 1.00 Max	Mn 2.00 Max	P 0.045 Max	S 0.030 Max	Ni 8.00 - 11.00	Cr 18.00 - 20.00	Mo - - -	Hardness (HRB) 90 max	YS (Ksi) 25 MIN.	TS (Ksi) 70 MIN.	EL % 35 MIN.	Hydro - Static test AT 5 SEC. MIN. (Psi)	Flat- tening (MM)	Wi spe (M
15	3/4" X SCH10S X 20FT.	10	79.03	FM062908502	0.035	0.564	1.214	0.039	0.010	8.055	18.368	-	83	65	94	40	2400	12.8	1
15	1/2" X SCH40S X 20FT.	63	494.20	FM242804514	0.035	0.307	1.725	0.036	0.010	8.075	18.076	-	83	68	95	41	3900	13.1	1
15	1/2" X SCH40S X 20FT.	37	290.24	FM242404515	0.035	0.322	1.744	0.036	0.010	8.074	18.084	-	83	70	98	41	3900	13.1	1
15	11/4" X SCH40S X 20FT.	25	523.90	FM012205511	0.035	0.325	1.585	0.028	0.009	8.165	18.356	-	84	69	96	39	2600	21.0	1
15	11/4" X SCH40S X 20FT.	5	104.78	FM012205512	0.035	0.325	1.585	0.028	0.009	8.165	18.356	-	84	69	97	39	2600	21.0	1
16	4.0" X SCH40S X 20FT.	4	397.63	FM160705512	0.035	0.386	1.469	0.024	0.011	8.097	18.272	-	84	70	100	39	1600	42.9	3
16	4.0" X SCH40S X 20FT.	8	795.25	FM160705511	0.035	0.420	1.489	0.025	0.010	8.093	18.323	-	85	71	101	38	1600	42.9	3
16	4.0" X SCH40S X 20FT.	4	397.63	FM160603511	0.035	0.561	1.671	0.032	0.009	8.098	18.085	-	85	72	99	39	1600	42.9	3
17	3.0" X SCH40S X 20FT.	18	1256.99	FM150708502	0.020	0.362	1.850	0.035	0.011	8.075	18.091	-	85	70	100	40	1900	36.9	2
17	3.0" X SCH40S X 20FT.	1	69.83	FM152304503	0.035	0.464	1.036	0.022	0.006	8.065	18.127	-	84	72	99	39	1900	36.9	2

PROCESS : WELDED
FINISH : ANNEALED AND PICKLED
TESTING : FLATTENING

RESULT : PASS
RESULT :
RESULT :
RESULT :
RESULT :

HEAT TREATMENT : 1050 C WATER QUENCHING
SURFACE & DIMENSIONAL CONTROL BY VISUAL ACCORDING TOA 999 : GOOD

WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HERE IN HAS BEEN MANUFACTURED AND TESTED IN ACCORDANCE WITH THE SPECIFICATION

DK
2-13-09

ASSURED BY : C. Medhon
QA DIVISION MANAGER

REMARK : MATERIAL FREE OF MERCURY CONTAMINATION NO WELD REPAIR

RF - QA - 011 2008/029/7

Rev. 2 : 09/50

MILL TEST REPORTS FURNISHED BY
MIDWEST SPECIALTY METALS, INC.
DATE 2-11-09 OUR ORDER NO. 10684
CUSTOMER Midwest / Imperial
YOUR P.O. Y08125-7122 /

3

FELKER BROTHERS CORPORATION

ISO 9001 CERTIFIED
22 North Chestnut Avenue · Marshfield, Wisconsin 54449
Telephone (715) 384-3121 · Fax (715) 387-6837

#10

MATERIAL TEST REPORT
Inspection Certificate
See Additional Tests for Dual Certification

PAGE NO.	1
ORDER NO.	249233
CUST. P.O. NO.	60-39427
DATE SHIPPED	12/20/08

LINE #	DESCRIPTION	HEAT NUMBER	CARBON	MANG.	PHOS.	SULFUR	SILICON	CHROMIUM	NICKEL	NITROGEN	MOLY	COPPER
5	TUBE A269/SA249 304L 6 OD .120	80600	.024	1.49	.027	.013	.51	18.21	8.17	.04	.32	.43

LINE #	HARDNESS	YIELD STRENGTH P.S.I.	TENSILE STRENGTH P.S.I.	ELONGATION TEST	ELONGATION %	ADDITIONAL TESTS
5	85 RB	37600	88600	2	62.0	ABCEFGHIJMNOQRV

MILL TEST REPORTS FURNISHED BY
MIDWEST SPECIALTY METALS, INC.
DATE 2-11-09 OUR ORDER NO. 10684
CUSTOMER Midwest / Imperial
YOUR P.O. Y08125-71221

ASTM Specification Revision Levels

A778 = 01	A774 = 06
A312 = 07	A403 = 07
A269 = 07	A249 = 07

Felker Brothers Corp. does not use mercury in the production nor in the testing of its products.

It is certified that all figures are correct as contained in the records of the company.

DK
2-13-09

Additional Tests:
- A. Solution Annealed 1900°F
- B. Tension Test
- C. Bend Test/Rev. Bend Test
- D. Hydrostatic Test
- E. Pickle/Passivated A380
- F. Eddy Current - (Weld) E426
- G. Etching (Weld)
- H. Dimensional
- I. Visual
- J. 304/304L Dual Certification
- K. 316/316L Dual Certification
- L. ASTM A 312/ASME SA 312
- M. Eddy Current - (Full Body) E426
- N. Flange Test
- O. Flattening/Rev. Flattening Test
- P. SA403
- Q. Corrosion - ASTM - A262 - Pass
- R. DIN 50049 3.1\EN 10204 3.1
- S. 100% Radiographic Exam SA/A312 S5
- T. 100% Radiographic Exam
- U. NACE MRO175
- V. PED 97/23/EC Annex1, Para 4.3

Q.C. REVIEWED

Scott Martinek-Quality Manager

ST 6.12 8/10

MILL TEST REPORTS FURNISHED BY
MIDWEST SPECIALTY METALS, INC.
DATE 2-11-09 OUR ORDER NO. 10684
CUSTOMER MIDWEST/Imperial
YOUR P.O. V08125-71221

#9

TCPW14577

Mill Test Report

EN 10204-3.1 / DIN 50049-3.1B

TA CHEN STAINLESS PIPE CO., LTD.
NO. 125 HSIN-TIEN 2ND ST.,
JENG-TEH, TAINAN, TAIWAN
TEL:(06)2793254 FAX:(06)2701382
COUNTRY ORIGIN:TAIWAN

Commodity : STAINLESS STEEL WELDED PIPE

Customer :TA CHEN INTERNATIONAL, INC.

Shipper : TA CHEN STAINLESS PIPE CO., LTD.

Specification : ASTM A312-2007/ASME SA312-2004/ASTM A999-2004a

Destination :

Grade : TP304/304L

Customer O/N :L23808/M49194990... **Certificate No** : IP0661003

Supply Condition: ANNEALED AND PICKLED

Factory O/N :QA0215626 **Date** : 2008/8/1 **INVOICE No** : QA02IP0661

Item No.	Case No. (Crate No.)	Heat No. Metal Source	Size	Quantity (Pcs)	Weight (Kgs)	C	Si	Mn	P	S	Ni	Cr	Mo	N
						Chemical Composition in %								
13	077,078,079	151100A TAIWAN	2" SCH10S 20'(6.1M) M49194990	75		0.022	0.420	1.430	0.033	0.005	8.060	18.140	-	0.037
14	[illegible]	246520 TAIWAN	2" SCH40S 20'(6.1M) M49194990	125		0.022	0.430	1.440	0.039	0.008	8.160	18.240	-	0.051
15	065,066,067,068	152391A TAIWAN	3" SCH10S 20'(6.1M) M49194990	45		0.021	0.400	1.480	0.038	0.004	8.090	18.140	-	0.040
16	0[illegible]58,059	152365 TAIWAN	3" SCH40S 20'(6.1M) M49194990	35		0.016	0.460	1.440	0.041	0.003	8.020	18.200	-	0.036
17	048,049,050,051,052,053	246722 TAIWAN	3-1/2" SCH10S 20'(6.1M) M49194990	60		0.016	0.440	1.510	0.032	0.004	8.120	18.290	-	0.039
18	044,045,046,047	246917A TAIWAN	3-1/2" SCH10S 20'(6.1M) M49194990	40		0.030	0.470	1.510	0.036	0.010	8.050	18.170	-	0.037
			Total	380										

Item No.	Tensile Test (Gage Lth x W.Lth=50mm x 12.5mm) 0.2% Yield Strength PSI	Tensile Strength PSI	Elongation %		Hardness Test HRB	Bend Test	Flattening Test	Heat Treatment TEMP. oF	Dimension And Surface Condition	Hydrostatic Test PSI	
13	44200	91300	49.00		82.00		OK	1960	OK	1400	
14	44600	94900	50.00		82.00		OK	1960	OK	1900	
15	45500	90100	51.00		82.00		OK	1960	OK	1000	
16	40300	86700	55.00		83.00		OK	1960	OK	1900	
17	40600	90000	50.00		85.00		OK	1960	OK	900	
18	47400	93900	50.00		84.00		OK	1960	OK	900	

Remarks

1. MERCURY FREE
2. EDDY CURRENT TEST : O.K.
3. ASTM A262E.: O.K.
4. NACE MR0175-03
5. FAR BAA - CANNOT CERTIFY COMPLIANCE
6. DFARS BAAS-CANNOT CERTIFY COMPLIANCE
7. FAR TAA-CANNOT CERTIFY COMPLIANCE

DK
2-13-09

We hereby certify the above statement to be true and correct every detail
TA CHEN has established a QMS according to ISO 9001, which is certified by LRQA (cert. no.TWN0936925)

George Yang
Manager of Inspection Section/George Yang

4

Pipe/Tube Manufactured by

Brismet

BRISTOL METALS LLC
IN BRISTOL, TN, USA

#11

MILL TEST REPORT

RM ID NUMBER
101529

SALES ORDER / RLS
002855 / 2

CERT ID / REV
00010908 / 01

QC REVIEWED
A Richards

CUSTOMER P.O.	CUSTOMER PART	HEAT NO.
2737846		826128

DESCRIPTION:408012003500100
8OD" WELDED TUBE .120" WALL TP304/TP304L (UNS# S30400/S30403) A249/A269

CERTIFICATION REQUIREMENTS

ENGINEERING
ASTM A249-04a/A269-04/ASME SA249-07, No ADD.

HYDRO PRESSURE
500 PSI

HEAT TREAT
Annealed at1900 Deg F. and water quenched to below 800 Deg. F. in less than 3 minutes.

Chemical

C	Cr	Mn	Ni	N	P	Si	S
.020	18.2	1.42	8.16	.07	.031	.45	.011

Mechanical

TEST	UNITS	RESULTS
Tensile PSI	PSI	91500
Yield PSI	PSI	43700
Elong %		58

Hardness

RB84

TEST	RESULT
Flattening	Pass
Revrs Flattening	Pass
TG Root Bend	Pass
Flare	Pass
Flange	Pass

JK
2-13-09

Certification is in accordance with EN10204:2004 type 3.1.
Chemical content is % by weight. Mechanical test results are in English units (inches and pounds)
No weld repairs have been performed on the base material.
Hardness in accordance with NACE MR0175 and MR0103 and material is free of cold work to enhance mechanical properties.
Pipe is Pickled and Passivated in accordance with ASTM A380.

MILL TEST REPORTS FURNISHED BY
MIDWEST SPECIALTY METALS, INC.
DATE 2-11-09 OUR ORDER NO. 10684
CUSTOMER Midwest / Imperial
YOUR P.O. Y08125 / 71221

We certify this report to be true and accurate, according to our records on file.
Bristol Metals has a Quality Management System in Place that is in compliance with ISO 9001:2000.
Bristol Metals does not add mercury during any manufacturing process.

Rick Duncan
Rick Duncan - Quality Assurance Mgr

ST/8..12/840 /826128/37846

dlc302z (v1.1)

Date Printed 09/05/2008

MILL TEST REPORT

This MTR contains 1 page (Page: 1)

MTR#: YC-L100121-01 Customer#: ASAI PO#: P37399 SO#: HP6217
Item#: .18860144304L#1 Bundle#: Z97080009-044 Heat#: 78S65314

MILL TEST REPORT

EN 10204-3.1 DIN 50049-3.1B

UKAS

TA CHEN STAINLESS PIPE CO., LTD.
NO. 125 HSIN-TIEN 2ND ST, HSIN-TIEN
JENG-TEH, TAINAN, TAIWAN
TEL: (06)2703254 FAX: (06)2701392
COUNTRY ORIGIN: TAIWAN

Commodity: PRIMARY HOT ROLLED STAINLESS STEEL PLATE AISI 304/304L NO1 FINISH

Customer:

Shipper:

Specification: ASTM A240/480
304/304L

Destination:

Customer's PO#: L24325 Certificate No.: YC-L100121-01 (Page 1:5)

Factory O/N: QA02I8006A Date: 10/02/08 Invoice No.: QA02IS0376

1AV

gy
2.12.09

Item No.	Bundle No.	Heat No.	Size	Quantity Pcs	Weight Kgs	Chemical Composition in % C	Si	Mn	P	S	Ni	Cr	Mo	N
* 1	Z97080009-025	78S65314	0.187" X 60.0" X 120"	9	1543	0.015	0.360	1.460	0.040	0.011	8.100	18.250		0.033
2	Z97080009-026	78S65314	0.187" X 60.0" X 120"	9	1543	0.015	0.360	1.460	0.040	0.011	8.100	18.250		0.033
3	Z97080009-027	78S65314	0.187" X 60.0" X 120"	9	1540	0.015	0.360	1.460	0.040	0.011	8.100	18.250		0.033
4	Z97080009-028	76S57069	0.187" X 60.0" X 120"	9	1554	0.016	0.480	1.470	0.042	0.004	8.040	18.160		0.035
5	Z97080009-044	78S65314	0.187" X 60.0" X 144"	8	1647	0.015	0.360	1.460	0.040	0.011	8.100	18.250		0.033

Item No.	Tensile Test: 0.2% Yield Strength PSI	Tensile Strength PSI	Elongation %	Reduction of Area %	Hardness Test HRB	Bend Test	Heat Treatment TEMP. °F	Dimension And Surface Condition
1	39200	85960	51		82		1930	
2	39200	85960	51		82		1930	
3	39200	85960	51		82		1930	
4	40460	90580	61		82		1930	
5	39200	85960	51		82		1930	

Remarks

1 TEST METHOD:
1.1 HEAT ANALYSIS C.S.N BY ASTM E1019-02, OTHERS BY ASTM E327-94/E 1086-94
1.2 TENSILE TEST ASTM E8-04
1.3 HARDNESS TEST: THICK. >12mm BY ASTM E18-02 OTHERS BY ASTM E92-97
2. INTERGRANULAR CORRSION PASSED
3. CERTIFIED FREE FROM MERCURY CONTAMINATION
4. CHEMICAL, TENSILE PROPERTIES AND HARDNESS COMPLIANCE WITH AMS5511 FOR 304L/AMS5513 FOR 304.
ASTM A240-06/A480-06.
ASME SA240-06/SA480-06 AND ASTM A666-03 ANNEALED.
ASME SA666-03 ANNEALED.
5. THIS CERTIFICATE COMPLIED TO 3.1/EN 10204:2004
6. SOURCE: YUSCO

We hereby certify the above statement to be true and correct every detail

TA CHEN STAINLESS PIPE CO., LTD.

Manager of Inspection Sector

DK
2-23-09

W/O 22856

PO Y08125-71169

76253

MILL TEST REPORT

TA CHEN INTERNATIONAL CORPORATION

www.tachen.com

This MTR contains 1 page (Page: 1)

MTR#: UGCL1673 Customer#: KENKEN PO#: 76253 SO#: CG7599
Item#: .18872144304L#1 Bundle#: 70501980 Heat#: 724018

UGINE & ALZ
ARCELOR GROUP

UGINE & ALZ Belgium NV
Maatschappelijke zetel
Genk-Zuid ; Zone 6A, Swinnenweijerweg 5, B 3600 Genk
Tel. (089) 30 21 11 - Telefax (089) 30 23 50
Telex 39098 alderg b
H.R. Tongeren nr 41.081 - B.T.W. nr BE 401.277.814

MILL CERTIFICATE BS EN 10204/3.1
CERTIFICAT DE RECEPTION NF EN 10204/3.1
ABNAHMEPRUEFZEUGNIS DIN EN 10204/3.1

Approved as supplier according to AD2000- WO - TRD 100 statement W II 603 certified acc. PED (97/23/ec) by TÜV, NB 0035

P.O. 27965

N-Nr-N 2007K0036289

UGCL1673

Manufacturer's works order number / N° de la commande usine productrice / Werksauftragsnummer	7UA699768/01-64035/397/01 Packing list:2007K722575
Surveyor's mark / Cachet de l'expert / Stempel des Werksachverstaendigen	U & A.
Purchaser and/or consignee / Client et/ou destinataire / Besteller und/oder Empfaenger	TA CHEN INTERNATIONAL CORP. 5855 OBISPO AVENUE 90805 LONG BEACH, CA USA
Purchaser's order number / N° de commande client / Kundenbestellnummer	L20636/785150
Customer article number / N° d'article client / Artikelnummer des Kunden	.18872144304L#1
Product - Produit - Erzeugnis	SHEETS, COLD ROLLED, SHOT BLASTED TOLES, LAMINEES A FROID, GRENAILLEES BLECHE, KALTGEWALZT, GESTRAHLT
Steel designation / Désignation de l'acier / Stahlbezeichnung	ASTM A 240(M)-07 TYPE 304L/304 ASME SA240 (M) 04A06 TYPE 304L/304
Finish / Présentation / Ausfuehrung	2D 2D
Steelmaking process / Mode d'élaboration de l'acier- Stahlherstellungsverfahren	Electric arc furnace-VOD/AOD-Continuous casting Four à arc-VOD/AOD-Coulée continue Elektro-Ofen-VOD/AOD-Stranggussanlage
Any supplementary requirements / Prescriptions supplémentaires - Zusätzliche Anforderungen	UNS S 30403
Product delivery condition / Etat de livraison du produit / Lieferzustand	Solution treated- Hypertrempe- Loesungsgegluehtabgeschreckt: 1050 C Forced air - Air forcé - Geblaeses Luft

ASTM A480/A480M-06B -- ASME SA 480-SA 480M-04 ADD.06

Coil n. / N° de bobine - Band Nr	Heat n. / N° de coulée - Schmelz Nr	Thickness / Epaisseur - Dicke	Width / Largeur - Breite	Length / Longueur - Laenge	Number of pieces / Nombre de pièces - Stueckzahl	Net weight / Poids net - Netto Gewicht
72401831	724018	4.76 mm 0.1870 "	1028.80 mm 72.000 "	3657.60 mm 144.00 "	35	8726 KG 19237 LBS

CHEMICAL ANALYSIS - ANALYSE CHIMIQUE - CHEMISCHE ZUSAMMENSETZUNG

	C	Si	Mn	Ni	Cr	Mo	Ti	N	S	P
Required-Exigé-Anforderung % mini				8.00	18.00					
% maxi	0.030	0.75	2.00	10.50	20.00			0.100	0.030	0.045
Cast Analysis / Analyse coulee / Analyse Schmelze	0.019	0.45	1.51	8.00	18.03			0.064	0.007	0.030

Tests to verify batch and quality have been carried out : OK
Tests de vérification de la conformité de la nuance fournie : OK
Verwechslungsprüfung wurde durchgeführt : OK

α Ferrite | δ Ferrite

Bend test results are satisfactory EN ISO 7438
Les essais de pliage sont satisfaisants 180 : ok
Ergebnisse des Biegeversuchs entsprechen den Vorschriften

MECHANICAL PROPERTIES - PROPRIETES MECANIQUES - MECHANISCHE WERTE ASTM A370

Room temperature - Température ambiante - Raumtemperatur | Test Temperature :

Location (1)	Direction (2)		Yield strength KSI Rp 0.2 %	Yield strength KSI Rp 1 %	Tensile strength KSI Rm	Elongation after fracture (A) % 50mm	Hardness HRB
		Required mini	30		75	40	
		Required maxi					92
1	T	Obtained	40	47	92	56	86

Impact strength test / Essai de résilience / Kerbschlagzähigkeitstest

Corrosion test / Test de corrosion / Korrosionstest: ASTM A262 E - 02A.R3:OK

R0.2(T)/R(T) % : 44

Sample Thickness: 4.69mm

Internal Cleanliness : A: B: C: D:

Location of the sample (1) / Emplacement de l'échantillon / Lage des Probeabschnittes
1. Front - Début - Anfang
2. Back - Fin - Ende
3. Middle - Milieu - Mitte

Direction of the test pieces (2) / Orientation des éprouvettes / Probenrichtung
T. Transverse - Travers - Quer
L. Longitudinal - long - laengs

The delivery is in accordance with the order
La fourniture est conforme aux exigences de la commande
Die Lieferung entspricht den Bestellbedingungen

Marking, inspection and measurement : without objection
Contrôle de marquage, d'aspect et de dimensions : satisfaisants
Pruefung der Stempelung, des Oberflaechenaspekts und der Abmessungen : ohne Beanstandung

Organisation inspection / Organisme et/ou service contrôle / Ueberwachungsabteilung
Metallurgical Department
29/06/2007 J. VANTRAPPEN

The Inspector / Le responsable / Der Werksachverstaendige

EQC601 29/07/2005

70501948, 56, 64, 72, 80

OK 1-27-09

This Material Complies To
SA 240
SB
SFA
Quality Control BM 1-7-09

8

Customer#:KENCLE MTR#:TICL2800 PO#:210183 SO#:LBR495 Invoice#:LAC151
Item#: 7GA60304L2B Bundle#: FA80858570N10 |

INSPECTION CERTIFICATE ORIGINAL

TICL 2800

Shanxi Taigang Stainless Steel CO.,LTD Member of Taiyuan Iron and Steel (Group) Co.,LTD
NO.2 jiancaoping,Taiyuan,Shanxi,P.R.China
TEL: (0351)3013328 FAX: (0351)3017816
http://www.tisco.com.cn
E_mail: tgbxg@tisco.com.cn

MILL TEST CERTIFICATE

CERTIFICATE NO.	ABA081115A
MATERIAL	AISI304/304L NO. 2B
SPECIFICATION	ASTM A240-04/A480-04, ASME SA240/A480 ASTM A666, AMS 5513-5511
L/C No.	

CUSTOMER	CONTRACT NO.	DATE OF ISSUE
Ta Chen International, Inc.	L24235	20080925

Product	Melting furnace	Inspectors stamp	Mark of the Manufacturer
COIL	E+VOD	★	Shanxi Taiyuan Stainless Steel Co.,ltd

NO.	Heat No.	Coil No.	Batch No.	Quantity	Dimensions (inch)	Weight(Pound)
15	A1802150	FA80858610N20	88346252	1	10GA × 60" × C	18843
16	A2802168	FA80858630N20	88346091	1	10GA × 60" × C	20450
17	A1802150	FA80858610N10	88346090	1	10GA × 60" × C	19637
18	A2801440	FA80556990N10	88346076	1	10GA × 60" × C	19791
19	A1802150	* FA80858570N10	88346615	1	7GA × 60" × C	20194
20	A1802150	FA80858580N20	88346484	1	7GA × 60" × C	17178
21	A1802150	* FA80858580N10	88346483	1	7GA × 60" × C	20481

Chemical Composition

Heat No.	C	Si	Mn	P	S	Cr	Ni	Cu	Al	N	Mo	Ti
A1802150	0.017	0.452	1.626	0.027	0.002	18.132	8.026	0.186		0.065	0.118	
A2802168	0.023	0.526	1.771	0.025	0.002	18.101	8.023	0.143		0.067	0.119	
A1802150	0.017	0.452	1.626	0.027	0.002	18.132	8.026	0.186		0.065	0.118	
A2801440	0.018	0.540	1.783	0.029	0.003	18.063	8.004	0.181		0.083	0.101	
A1802150	0.017	0.452	1.626	0.027	0.002	18.132	8.026	0.186		0.065	0.118	
A1802150	0.017	0.452	1.626	0.027	0.002	18.132	8.026	0.186		0.065	0.118	
A1802150	0.017	0.452	1.626	0.027	0.002	18.132	8.026	0.186		0.065	0.118	

Mechanical Properties (Test temperature :20℃)

Test No.	Tensile Rm N/mm²	$R_{P0.2}$ Yield$_{0.2\%}$ N/mm²	$R_{P1.0}$ Yield$_{1.0\%}$ N/mm²	Elongation A5 (%)	Elongation A50(%)	Corrosion Tests	Hardness HRB	Hardness HV	Hardness HRC
88346252-T	590	282			56		80.5-81.0		
88346091-T	605	292			57		84.5-84.0		
88346090-T	590	282			56		80.5-81.0		
88346076-T	595	296			52		83.5-84.0		
88346615-T	610	337			57		79.5-79.0		
88346484-T	595	291			57		74.5-75.0		
88346483-T	595	291			57		74.5-75.0		

SPECTROMETER SORTING TEST: OK
EN 10204-3.1B

Place: Taiyuan

3-4-09

Work Inspector: 李忠新

ENTERED

FEB 09 2009

#1 #4

NAS

6870 HIGHWAY 42 EAST

METALLURGICAL TEST REPORT

NORTH AMERICAN STAINLESS
6870 HIGHWAY 42 EAST
GHENT, KY 41045

Certificate: 413421 3

Customer: 005518 001

Mail To:
JACQUET MID-WEST
1908 DEKOVEN
RACINE, WI 53403

Ship To:
JACQUET MID-WEST
1908 DEKOVEN
RACINE, WI 53403

Date: 7/21/2008 Page: 1

Steel: 304/304L

Finish: HRAP

Your Order: 2149

NAS Order: IN 0047468 02

Corrosion: ASTM A262/02aE;180Bend-OK

PRODUCT DESCRIPTION:

STAINLESS STEEL PLATE, HOT ROLLED, ANNEALED AND PICKLED.
ASTMA240/07,480/06b,666/03,ASMESA240/04,480/04,SA666/04
QQS766D-A X MGPRM,AMS5511H/AMS5513H XMRK,MIL4043B,AMD3,X CRNMEAS
Chem only for: ASTM A276/A312/A479/A484, ASME SA312/SA479
ASME Sect. II, 1995 Edition, 1996 & 1997 Addenda

REMARKS:

Mat'l Free of Mercury Contamination. No weld repairs.
EN 10204 3.1; QQS763F Cond A; RoHS Compliant
* Melted & Manufactured in the USA
NACE MR0103-2005;NACE MR0175-2001; EN10204 3.1b
Minimum solution anneal 1900 F.,Water Quenched

Product Id	Plate#	Skid #	Thickness	Width	Weight	-------Length------		Mark	Pieces	Commodity Code
043YR1 DB	043YR1 DB	P66997	.4960	60.0000	2,100	PLATE	240.00	3	1	

CHEMICAL ANALYSIS CM(Country of Melt) ES(Spain) US(United States) ZA(South Africa)

HEAT	CM	C	CR	CU	MN	MO	N	NI	P	S
3YR1	US	.0219	18.3056	.3712	1.6931	.2711	.0749	8.1305	.0298	.0006
		SI								
		.3500								

MECHANICAL PROPERTIES

Product Id#	Plate#	l o c	d i r	UTS KSI	.2% YS KSI	ELONG %-2"	Hard RB	R of A %
043YR1 DB	043YR1 DB	F	T	86.49	38.46	64.40	84.00	75.53

DK
3-10-09

JACQUET NO.
-10163

NAS hereby certifies that the analysis on this certification is correct and the material meets the specifications stated.

QC ENGINEER ERIC HESS 7/21/2008

#2 #7
fiche # 10017 - 10018

NAS NORTH AMERICAN STAINLESS

METALLURGICAL TEST REPORT

6870 Highway 42 East
Ghent, KY 41045-9615
(502) 347-6000

Certificate: 377887 01

Customer: 5518 001

Mail To:
JACQUET MID-WEST
1908 DEKOVEN
RACINE, WI 53403

Ship To:
JACQUET MID-WEST
1908 DEKOVEN
RACINE, WI 53403

Date: 11/28/2007 Page: 1

Steel: 304/304L

Finish: HRAP

Your Order: TERRY

NAS Order: AN 0379335 01

Corrosion: ASTM A262/02aE;180Bend-OK

PRODUCT DESCRIPTION:

STAINLESS STEEL PLATE, HOT ROLLED, ANNEALED AND PICKLED.
ASTMA240/07,480/06b,666/03,ASMESA240/04,480/04,SA666/04
QQS766D-A X MGPRM,AMS5511H/AMS5513H XMRK,MIL4043B,AMD3,X CRNMEAS

REMARKS:

Mat'l Free of Mercury Contamination. No weld repairs.
EN 10204 3.1; QQS763F Cond A; RoHS Compliant

Skid #	Prod #	Thickness	Width	Weight	---------Length--------	Mark	Pieces
P59018	* 022YP7	.3750	60.0000	3,270 PLATE	240.00		2
P59019	* 022YP7	.3750	60.0000	3,270 PLATE	240.00		2

CHEMICAL ANALYSIS CM(Country of Melt) ES(Spain) US(United States) ZA(South Africa)

Heat	CM	C	CR	CU	MN	MO	N	NI	P	S	SI
2YP7	US	.018	18.208	.312	1.726	.303	.083	8.290	.030	.001	.381

MECHANICAL PROPERTIES

Skid #	Prod #	loc	dir	UTS KSI	.2% YS KSI	ELONG %-2"	Hard RB
P59018	022YP7	F	T	87.35	37.64	60.01	81.50
P59019	022YP7	F	T	87.35	37.64	60.01	81.50

OK
3-10-09

NAS hereby certifies that the analysis on this certification is correct and the material meets the specifications stated.

QC ENGINEER 11/28/2007
ERIC HESS

#3

QUET NO.
-10199

注文者 Shipper : KANEMATSU CORPORATION
注文者照合番号 Reference No. : TJB15 00006004
契約番号 Contract No. : 8-868-TH-5-5-BH24
品名 Commodity : HOT ROLLED STAINLESS STEEL PLATES
規格 Specification : ASTM A240-05A TYPE304/304L/ASME SA-240 TYPE304/304L-2005A
文書番号 Document No. :

新日鐵住金ステンレス株式会社
Nippon Steel & Sumikin Stainless Steel Corporation

鋼材検査証明書
INSPECTION CERTIFICATE

本社 Head Office :〒100-0004 東京都千代田区大手町二丁目６番１号 2-6-1, Otemachi,Chiyoda-ku,Tokyo 100-0004,Japan
八幡製造所 Yawata Works :〒805-0058 北九州市八幡東区大字前田字波戸２１０８－１ 2108-1, Azahato, Oazamaeda,Yawatahigashi-ku, Kitakyushu-City,805-0058,Japan

証明書番号 Certificate No. : 2600　頁 Page : 1
発行年月日 Date Of Issue : 2008-06-11

需要家 Customer : JACQUET MIDWEST INC.
需要家管理番号 Customer's Control No. : PO 2069 REV02　E05 2 3SSSRW 026 *

寸法 Dimension mm	員数 Quantity	質量 Mass LBS KG	製鋼番号 Heat No. / 試験番号 Test No.	製品番号 Plate No.	Location Orientation *1	耐力 Y.S 0.2% KSI	引張強さ T.S KSI	伸び EL %	% *3	Bend *4	Impact Avg	Impact Each	HBW 10/1500	C x100 x10³	Si x100	Mn x100	P x10³ / N x100	S x10³ / Ti x100	Cu x100	Ni x100	Cr x100	Mo x100	Nb x100	V x100	T.Al x10³	Ceq x100	供給状態 Delivery Conditions *7
				SPEC. MIN. MAX.		30	75	40					201	30	75	200	45	30		800 1050	1800 2000						
				MAX.													10										
			CUSTOMER'S	SPEC. MIN. MAX.		30	75 100	400					192	30	75	200	40	30	75	800 1050	1800 2000	40					
				MAX.													10										
0.750"X96"X240" 01	1		E80215 35923	710995-01	TCH	37	84	645					140	19	37	129	28 5	3 0	21	905	1810	11	2				
TOTAL	1	5009 2272																									

SOLUTION HEAT TREATMENT........1055C X 5MIN. WATER COOLED
CORROSION TEST (ASTM A262 PRACTICE-E): ACCEPTABLE
VISUAL & DIMENSIONAL INSPECTION : ACCEPTABLE
NO WELD REPAIR / FREE OF MERCURY CONTAMINATION / MADE IN JAPAN
ASTM A480-05/ASME SA480-05A, NACE MR0175-03, AMS5513G/5511G
AS PER EN 10204 CERTIFICATE ON MATERIAL TESTS 3.1

注釈 Notes *1 Location-Orientation 位置・方向 T:頭部 Top, B:底部 Bottom, L:圧延方向 Longitudinal, C:直角方向 Transverse, Z:板厚方向 Through Thickness, R:45° 方向 45Deg. to the Longitudinal Axis
*2 G.L標点距離Gage Length, A:50mm平形試験片Rectangular, B:50mm丸形試験片Round, C:70mm平形試験片Rectangular, D:70mm丸形試験片Round, E:80mm平形試験片Rectangular, F:80mm丸形試験片Round, G:200mm, H:2", I:8", J:5.65√So
*3 R.A:絞り Reduction Of Area, Y.R:降伏比 Yield Ration *4 A:合格 Acceptable *5 2:2.5mm, 3:3.3mm, 4:3.33mm, 5:5.0mm, 6:6.67mm, 7:7.5mm, 8:6.7mm, 9:製品板厚 Plate Thickness *6 P:製品分析 Product Analysis
*7 N:焼準 Normalized, Q:焼入れ Quenched, T:焼戻し Tempered, CR:Controlled Rolled, NIC:NIC Process, CLC:CLC Process
SH:延性破面率 Shear Fracture, CF:脆性破面率 Crystallinity Fracture, LE:横膨出 Lateral Expansion, AGS:オーステナイト粒度 Austenite Grain Size, FGS:フェライト粒度 Ferrite Grain Size, SR:Stress Relieved /Post Weld Heat Treatment

上記注文品は御指定の規格または仕様に従って製造され、その要求事項を満足していることを証明します。　327

WE HEREBY CERTIFY THAT THE MATERIAL DESCRIBED HEREIN HAS BEEN MADE IN ACCORDANCE WITH THE RULES OF THE CONTRACT.

JK
3-10-09

I. Tanaka
八幡製造所
厚板管理室長
Group Manager,Plate Quality Control Dept.
Yawata Works

Y16-02-2 Rev. 4

#5

JACQUET NO.
-10201

JACQUET NO.
-10202

ACRONI

ACRONI, d.o.o.
Cesta Borisa Kidriča 44
SI - 4270 Jesenice
T: +386 4 584 10 00
F: +386 4 584 11 11
E: uprava@acroni.si
W: http://www.acroni.si

Potrdilo o prevzemu 3.1 / Abnahmeprüfzeugnis 3.1 / Inspection Certificate 3.1 EN 10204 3.1 Stran/Seite/Page 1/2

Št./Nr./no. **31092217-1** — Datum/Datum/Date 30.7.2008

Naročilo/Bestellung/Order 2096disp.27830 — Dobavni list/Lieferschein/Despatch N. 31092217 from30.7.2008

Izdelek/Erzeugnis/Product Plates — Vrsta peči/M. Furnace E+VOD

Naročnik/Kunde/Customer

JACQUET MID WEST 1908
DE KOVEN AVENUE W153403
RACINE
UNITED STATES

	Znak izvedenca TK	Znak proizvajalca

Specifikacije/Vorschriften/Specifications	Tip/W.Nr./Type	Pov./Flache/Finish	Kor.test/Int.krist.korr./Corrosion test
ASTM A 240/A 240M/ED.04 ,ASTM A480	304L/304	No.1	ASTM A262PRACTICE:OK
ASME SA 240 SECT.II PART A/ED-01	304L/304	No.1	
ASME SA 480			
ASM 5513 H			

Obseg dobave / Umfang der Lieferung / Extent of mat. delivery

Poz.Pos.Item	Šarža/Schmelzen Nr./cast No.	Št.plošče/Walztafel /Plate No	Teža/Gewicht/ Wieght	Dimenzije/Abmessungen/Dimensions	Št.Stuck/Q.	Št. V.Pr. Nr.
3	264442	88225	5593	2.250x79x240	1	88225
4	264446	88253	5593	4.000x79x135	1	88253

Mehanske lastnosti/Mechanische Eigenschaften/Mechanical properties

Št.vzorca Sample No.	Smer vzorca Position	Nap. tečenja 0.2 % Yield 0.2% KSI	Nap. tečenja 1% Yield 1% KSI	Nat. Trdnost Tensile KSI	Raztezek A5 % Elongation	Raztezek A50 % Elongation	Trdota Hardness Rockwell B HRcB	Žil.1 Impact FtLb	Žil.2 Impact FtLb	Žil.3 Impact FtLb	Temp. °F
88225	P	44.36	53.06	89.31	45.9	72.2	87	279	284	283	68
88253	P	42.04	49.44	80.90	52.5	77.1	80	253	262	258	68

JK 3-10-09

SIJ skupina Slovenska industrija jekla

ACRONI
ACRONI, d.o.o.
Cesta Borisa Kidriča 44, 4270 Jesenice
Član skupine SIJ
Member of Slovenian Steel Group

19/72

V3

#5

ACRONI

ACRONI, d.o.o.
Cesta Borisa Kidriča 44
SI - 4270 Jesenice
T: +386 4 584 10 00
F: +386 4 584 11 11
E: uprava@acroni.si
W: http://www.acroni.si

Potrdilo o prevzemu 3.1 / Abnahmeprüfzeugnis 3.1 / Inspection Certificate 3.1

št./Nr./no. : **31092217-1**

Kemična analiza/Chemische Zusammensetzung/Chemical composition

Šarža	%C	%Si	%Mn	%P	%S	%Cr	%Co	%Ni	%Mo	%Ti	%N	%B
264446	0.011	0.31	1.56	0.035	0.002	18.13	0.08	8.16			0.0896	0.0006
264442	0.014	0.34	1.51	0.040	0.001	18.15	0.11	8.15			0.0991	0.0005

Opombe/Remarks

HEAT TREATMENT : QUENCHED AT 1050°C, WATER QUENCHED
- VISUAL AND DIMENSIONAL CHECK : OK
- SPECTROMETER SORTING TEST : OK
- INTERGRANULAR CORROSION TEST ACCORDING TO
ASTM A .- 262 PRACTICE E : OK!
NO WELD REPAIR.
MERCURY FREE.

DK
3-10-09

skupina SIJ Slovenska industrija jekla

ACRONI
ACRONI, d.o.o.
Cesta Borisa Kidriča 44, 4270 Jesenice
Član skupine SIJ
Member of SIJ Group
19/72

49

#6

ACRONI

JACQUET NO. -10203

JACQUET NO. -10204

ACRONI, d.o.o.
Cesta Borisa Kidriča 44
SI - 4270 Jesenice
T: +386 4 584 10 00
F: +386 4 584 11 11
E: uprava@acroni.si
W: http://www.acroni.si

Potrdilo o prevzemu 3.1 / Abnahmeprüfzeugnis 3.1 / Inspection Certificate 3.1 EN 10204 3.1 Stran/Seite/Page 1/2 št./Nr./no. **31092103-1** Datum/Datum/Date 28.7.2008 Naročilo/Bestellung/Order 2096disp.27830 Dobavni list/Lieferschein/Despatch N. 31092103 from28.7.2008 Izdelek/Erzeugnis/Product Plates Vrsta peči/M. Furnace E+VOD	Naročnik/Kunde/Customer JACQUET MID WEST 1908 DE KOVEN AVENUE W153403 RACINE UNITED STATES

JACQUET NO. -10205

	Znak izvedenca TK	Znak proizvajalca

Specifikacije/Vorschriften/Specifications	Tip/W.Nr./Type	Pov./Flache/Finish	Kor.test/Int.krist.korr./Corrosion test
ASTM A 240/A 240M/ED.04 ,ASTM A480	304L/304	No.1	ASTM A262PRACTICE:OK
ASME SA 240 SECT.II PART A/ED-01	304L/304	No.1	
ASME SA 480			
ASM 5513 H			

Obseg dobave / Umfang der Lieferung / Extent of mat. delivery

Poz.Pos.Item	Šarža/Schmelzen Nr./cast No.	Št.plošče/Waltztafel /Plate No	Teža/Gewicht/ Wieght	Dimenzije/Abmessungen/Dimensions	Št.Stuck/Q.	Št. V.Pr. Nr.
1	264446	88502	2175	0.875x79x240	1	88502
2	264442	88293	2485	1.000x79x240	1	88293
2	264442	88294	2485	1.000x79x240	1	88294

Mehanske lastnosti/Mechanische Eigenschaften/Mechanical properties

Št.vzorca Sample No.	Smer vzorca Position	Nap. tečenja 0.2 % Yield 0.2% KSI	Nap. tečenja 1% Yield 1% KSI	Nat. Trdnost Tensile KSI	Raztezek A5 % Elongation	Raztezek A50 % Elongation	Trdota Hardness Rockwell B HRcB	Žil.1 Impact FtLb	Žil.2 Impact FtLb	Žil.3 Impact FtLb	Temp. °F
88502	P	40.74	48.86	86.41	56.1	81.0	86	255	259	259	68
88293	P	41.90	51.03	87.57	48.9	73.0	86	271	276	263	68
88294	P	41.03	50.31	87.43	54.1	80.8	86	278	286	283	68

DK 3-10-09

SIJ skupina Slovenska industrija jekla

ACRONI
ACRONI, d.o.o.
Cesta Borisa Kidriča 44, 4270 Jesenice
Member of Slovenian Steel Group

19/72

15

#6

ACRONI

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SI - 4270 Jesenice
T: +386 4 584 10 00
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E: uprava@acroni.si
W: http://www.acroni.si

Potrdilo o prevzemu 3.1 / Abnahmeprüfzeugnis 3.1 / Inspection Certificate 3.1

Št./Nr./no. : **31092103-1**

Kemična analiza/Chemische Zusammensetzung/Chemical composition

Šarža	%C	%Si	%Mn	%P	%S	%Cr	%Co	%Ni	%Mo	%Ti	%N	%B
264446	0.011	0.31	1.56	0.035	0.002	18.13	0.08	8.16			0.0896	0.0006
264442	0.014	0.34	1.51	0.040	0.001	18.15	0.11	8.15			0.0991	0.0005

Opombe/Remarks

HEAT TREATMENT : QUENCHED AT 1050°C, WATER QUENCHED
- VISUAL AND DIMENSIONAL CHECK : OK
- SPECTROMETER SORTING TEST : OK
- INTERGRANULAR CORROSION TEST ACCORDING TO
  ASTM A .- 262 PRACTICE E : OK!

NO WELD REPAIR.
MERCURY FREE.

JK
3-10-09

ACRONI
ACRONI, d.o.o.
Cesta Borisa Kidriča 44, 4270 Jesenice
Član skupine SIJ
Member of Slovenian Steel Group
19/72
Družba je registrirana pri okrožnem sodišču v Kranju
Številka vložka: 1/04172/00
Osnovni kapital družbe: 8.627.530.469,40 SIT
Matična številka: 5682418
Identifikacijska številka za DDV: SI25810754

Certificate of Mill Test Results
BL TO-004716-001 11Apr
Pg 1/1

JACQUET NO.	JACQUET NO.	JACQUET NO.
-10097	-10098 #8 #9	-10099

ThyssenKrupp Acciai Speciali Terni S.p.A.
con Unico Socio
Società diretta e coordinata dalla ThyssenKrupp Stainless GmbH
Viale B. Brin, 218 – 05100 Terni, Italia

14212001

CERTIFICATO DI COLLAUDO
INSPECTION CERTIFICATE
CERTIFICATE DE RECEPTION
ABNAHMEPRÜFZEUGNIS B*

EN 10204/3.1 0749357 PAG. 1/ 4

SPECIFICA: / SPECIFICATION / ANFORDERUNGEN:
ASTM A 240/01A
ASME SA 240/01
QQS 766 D/88
ASTM A 480/99B

ORDINE CLIENTE N° / CUSTOMER ORDER N° / COMMANDE DU CLIENT N° / BESTELLUNG Nr: OG 420

CLIENTE / CUSTOMER / CLIENT / BESTELLER:
THYSSENKRUPP ACCIAI SPECIALI TERNI
2275 HALF DAY ROAD SUITE #300
BANNOCKBURN IL
60015 USA

ORDINE INTERNO N° / INTERNAL ORDER N° / COMMANDE INT N° / WERKS Nr: 8E070653
THYSSENKRUPP AST USA
MISSISSAUGA WAREHOUSING LTD -
MISSISSAUGA, ONTARIO L4Y 1Y6
0 CANADA

PRODOTTO: / PRODUCT: / PRODUIT: / PRÜFGEGENSTAND: STAINLESS STEEL PLATES FROM COIL

AVV. DI SPEDIZ. N° / SHIPPING NOTICE N° / AVIS D'EXPEDITION N° / VERSANDANZEIGE Nr: CE070557

COMPOSIZIONE CHIMICA - CHEMICAL COMPOSITION - COMPOSITION CHIMIQUE - CHEMISCHE ZUSAMMENSETZUNG

N° ROTOLO / COIL N° / N° BOBINE / BAND Nr.	N° COLATA / HEAT N° / N° COULEE / SCHMELZE Nr	% C	% Mn	% Si	% P	% S	% Cr	% Ni	% Mo	% N	% Ti	% Cu	%	%
433806	0579775	.030	1.63	.370	.029	.001	18.00	8.000	.410	.064		.270		

Material free from: Cuban origin Nickel-weld repair-mercury cont-rohs free matl

TIPO D'ACCIAIO: / STEEL TYPE: / TYPE D'ACIER: / MARKENBEZEICHNUNG: AST 304DL
304L
304L
304L
304 - 304L 304L

TIMBRO DEL PRODUTTORE: / PRODUCER TRADE MARK / MARQUE DU PRODUCTEUR / ZEICHEN DES LIEFERWERKS: ThyssenKrupp Acciai Speciali Terni S.p.A.

TIMBRO DEL RESPONSABILE INCARICATO / INSPECTOR STAMP / MARQUE DU RESPONSABLE CHARGE / STEMPEL DES WERKSSACHVERSTÄNDIGEN

513 C.P.C. INOX S.p.A.

TRATT. TERMICO - RICOTTURA DI SOLUBILIZZ. 1050^C ARIA-ACQUA NEBULIZZATA-ACQUA
HEAT TREATMENT - ANNEALING; AIR - WATER SPRAY - WATER COOLING
TRAITEMENT - THERMIQUE - HYPERTREMPE; AIR - EAU ATOMISEE - EAU
WÄRMEBEHANDLUNG - ABSCHRECKEN: LUFT - SPRÜHWASSER - WASSER

PROCESSO DI ELABORAZIONE: E + AOD + CC
STEELMAKING PROCESS
PROCEDE D'ELABORATION
ERSCHMELZUNGSART

IL MATERIALE È RESISTENTE ALLA CORROSIONE INTERGRANULARE SECONDO:
THE MATERIAL IS RESISTANT TO INTERCRYSTALLINE CORROSION IN ACCORDANCE WITH:
LE MATERIEL EST RESISTANT A LA CORROSION INTERGRANULAIRE SELON:
DIE OBENGENANNTE SCHMELZE IST BESTÄNDIG GEGEN INTERKRISTALLINE KORROSION GEMÄSS

RISULTATI DELLE PROVE / TEST RESULTS / RESULTATS DES ESSAIS / ERGEBNIS DER PRÜFUNGEN (1 N/mm = 1 M Pa)

N° COLLO / PACKAGE N° / N° COLIS / KISTEN Nr.	N° ROTOLO / COIL N° / N° BOBINE / BAND Nr.	DIMENSIONI / DIMENSIONS / ABMESSUNGEN INCHES	N° PEZZI / PIECES	FINITURA / FINISH / FINITION / AUSFÜHRG	PESO / WEIGHT / POIDS / GEWICHT LBS	(1)	(2)	Rp 0.2% KSI	Rp 1%	Rm KSI	A % Lo = 2"	A % Lo = 80	A % Lo = 4.5	DUREZZA / HARDNESS HRB		PIEGA / BEND	GRANO / GRAIN (size)
CARATTERISTICHE RICHIESTE - REQUIRED CHARACTERISTICS - CHARACTERISTIQUES REQUISES - ANFORDERUNGEN								≥ 25	≥	> 70	≥	≥	≥	≤ 88	≤		
C71782	433806	240 X60.000X 120	7	1NAC	3514	T	T	45		90	52.1		53.0	88.0			
C71782						C	T	45		90	51.1		52.0	88.0			
C71783	433806	240 X60.000X 120	7	1NAC	3514	T	T	45		90	52.1		53.0	88.0			
C71783						C	T	45		90	51.1		52.0	88.0			
C71784	433806	240 X60.000X 120	7	1NAC	3522	T	T	45		90	52.1		53.0	88.0			
C71784						C	T	45		90	51.1		52.0	88.0			
C71785	433806	240 X60.000X 120	7	1NAC	3522	T	T	45		90	52.1		53.0	88.0			
C71785						C	T	45		90	51.1		52.0	88.0			
C71786	433806	240 X60.000X 120	7	1NAC	3518	T	T	45		90	52.1		53.0	88.0			
C71786						C	T	45		90	51.1		52.0	88.0			

Certifichiamo che i prodotti sopra elencati sono conformi alle prescrizioni dell'ordine.
We certified products listed above comply with order requirements.
Nous certifions que les produits cités ici sont conformes aux prescriptions de la commande.
Wir bestätigen, dass die Lieferung den Vereinbarungen der Bestellung entspricht.

COMPLIES WITH ED 2000/53/EC

ThyssenKrupp Acciai Speciali Terni S.p.A.
FIRMA DEL RESPONSABILE INCARICATO / INSPECTOR SIGNATURE / SIGNATURE DU RESPONSABLE CHARGE / UNTERSCHRIFT DES WERKSSACHVERSTÄNDIGEN

Certificato emesso automaticamente

1) Sampling - Location - Ort
T = Testa - Top - Tête - Kopf
C = Coda - Bottom - Pied - Fuss

2) Senso - Direction - Richtung
T = Trasversale - Transverse - Traverse - Quer
L = Longitudinale - Longitudinal - Long - Längs

MARCATURE: / MARKING: / MARQUAGE: / KENNZEICHNUNG: Wrs.-Type / Heat n° - Coil N° / Thickness - Finish

TERNI, LI 01-08-2007 L. ROTINI

DK
3-10-09

OLBERT METAL SALES LIMITED
PO/Rel 3913
OLBERT METAL SALES INC
STAINLESS HR PLATE 304L
.250" NOM X 60.0000" X 120.0000"
PART NO.

#1

02/26/09

ThyssenKrupp Materials NA
Ken-Mac Metals Division
ThyssenKrupp

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Part No:
Ken-Mac Order/Item: 142430-1
Item Description : SS .500 2.000 2.000 304L ANN HRAP HRAP

==

Heat/Lot: 3YR1 Mill Tag No : 10163
KM Stock No: 212321 Case Tickets: 194405

<---------------------------------- Chemical Composition ---------------------------------->

(C)	(Mn)	(P)	(S)	(Si)	(Cr)	(Ni)	(Mo)	(Cu)	(Al)
.0219	1.6931	.0298	.0006	.3500	18.3050	8.1300	.2711	.3712	

<---------------------------------- Mechanical Composition ---------------------------------->

Tensile PSI: 86,490 Yield PSI: 38,460 Elongation: 64.4 Hardness as Shipped: 84RB

JK
3-10-09

==

Total Pounds: 7 A Page 1

BH

Bob Harley - Corporate Quality Manager

To the best of our knowledge, the aformentioned material conforms to all applicable standards

18

ThyssenKrupp Materials NA
Ken-Mac Metals Division

ThyssenKrupp

#2

02/26/09

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Part No:
Ken-Mac Order/Item: 142430-2
Item Description : SS .375 12.000 25.000 304L ANN HRAP HRAP

==

Heat/Lot: 2YP7 Mill Tag No : 10018
KM Stock No: 212322 Case Tickets: 194406

<---------------------------------- Chemical Composition ---------------------------------->

(C)	(Mn)	(P)	(S)	(Si)	(Cr)	(Ni)	(Mo)	(Cu)	(Al)
.0180	1.7260	.0300	.0010	.3810	18.2080	8.2900	.3030	.3120	

<--------------------------------- Mechanical Composition --------------------------------->

Tensile PSI: 87,350 Yield PSI: 37,640 Elongation: 60.0 Hardness as Shipped: 81.5RB

JK 3-10-09

==

Total Pounds: 103 A Page 1

Bob Harley - Corporate Quality Manager

version 9.2.17 - page 193

To the best of our knowledge, the aformentioned material conforms to all applicable standards

M

02/26/09

ThyssenKrupp Materials NA
Ken-Mac Metals Division

#4

ThyssenKrupp

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Part No:
Ken-Mac Order/Item: 142430-4
Item Description : SS .500 4.000 11.250 304L ANN HRAP HRAP

==

Heat/Lot: 3YR1 Mill Tag No : 10163
KM Stock No: 212324 Case Tickets: 194408

<---------------------------------- Chemical Composition ---------------------------------->

(C)	(Mn)	(P)	(S)	(Si)	(Cr)	(Ni)	(Mo)	(Cu)	(Al)
.0219	1.6931	.0298	.0006	.3500	18.3050	8.1300	.2711	.3712	

<---------------------------------- Mechanical Composition ---------------------------------->

Tensile PSI: 86,490 Yield PSI: 38,460 Elongation: 64.4 Hardness as Shipped: 84RB

3-10-09

==

Total Pounds: 108 A Page 1

Bob Harley - Corporate Quality Manager

Version 3.2.1 - page 194

To the best of our knowledge, the aformentioned material conforms to all applicable standards

ThyssenKrupp Materials NA
Ken-Mac Metals Division

ThyssenKrupp

#3

02/26/09

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Part No:
Ken-Mac Order/Item: 142430-3
Item Description : SS .750 4.000 4.000 304L ANN HRAP HRAP

===

Heat/Lot: E80215 Mill Tag No : 10199
KM Stock No: 212323 Case Tickets: 194407

<---------------------------------- Chemical Composition ---------------------------------->

(C)	(Mn)	(P)	(S)	(Si)	(Cr)	(Ni)	(Mo)	(Cu)	(Al)
.0190	1.2900	.0280	.0030	.0370	18.0000	9.0500	.0110	.0210	

<---------------------------------- Mechanical Composition ---------------------------------->

Tensile PSI: 84,000 Yield PSI: 37,000 Elongation: 64.5 Hardness as Shipped: 76.5RB

JK
3-10-09

===

Total Pounds: 29

A Page 1

BH

Bob Harley - Corporate Quality Manager

version 9.1.1 - page 1

To the best of our knowledge, the aformentioned material conforms to all applicable standards

w

ThyssenKrupp Materials NA
Ken-Mac Metals Division

ThyssenKrupp

#5 #6

03/06/09

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Ken-Mac Order/Item: 142624-1
Item Description : SS .999 35.500 CR 304L ANN HRAP HRAP

Part No:

==

Heat/Lot: 264442 Mill Tag No : 88225 #5
KM Stock No: 212984 Case Tickets: 194844

*** CERTIFICATION INCOMPLETE *** - COULD NOT FIND ACTUAL CERTIFICATIONS

==

Heat/Lot: 264446 Mill Tag No : 88502 #6
KM Stock No: 212983 Case Tickets: 194843

*** CERTIFICATION INCOMPLETE *** - COULD NOT FIND ACTUAL CERTIFICATIONS

JC 3-10-09

==

Total Pounds: 434 A Page 1

BH

Bob Harley - Corporate Quality Manager

To the best of our knowledge, the aformentioned material conforms to all applicable standards

02/26/09

ThyssenKrupp Materials NA
Ken-Mac Metals Division
ThyssenKrupp

#7

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Part No:
Ken-Mac Order/Item: 142431-3
Item Description : SS .375 3.000 5.000 304L ANN HRAP HRAP

==========

Heat/Lot: 2YP7 Mill Tag No : 10018
KM Stock No: 212325 Case Tickets: 194404

<---------- Chemical Composition ---------->

(C)	(Mn)	(P)	(S)	(Si)	(Cr)	(Ni)	(Mo)	(Cu)	(Al)
.0180	1.7260	.0300	.0010	.3810	18.2080	8.2900	.3030	.3120	

<---------- Mechanical Composition ---------->

Tensile PSI: 87,350 Yield PSI: 37,640 Elongation: 60.0 Hardness as Shipped: 81.5RB

JK 3-10-09

==========

Total Pounds: 2 A Page 1

BH

Bob Harley - Corporate Quality Manager

To the best of our knowledge, the aformentioned material conforms to all applicable standards

23

ThyssenKrupp Materials NA
Ken-Mac Metals Division

ThyssenKrupp

#8 #9

02/26/09

CERTIFIED CHEMICAL & MECHANICAL ANALYSIS

Sold To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Ship To: Midwest Imperial Steel Fab LLC
400 S. Lagrange Rd Unit C

Frankfort IL 60423

Customer PO Number: Y08125-71222
Part No:
Ken-Mac Order/Item: 142431-1
Item Description : SS .250 6.000 CR 304L ANN HRAP HRAP

==

Heat/Lot: 0579775 Mill Tag No : 10099
KM Stock No: 212326 Case Tickets: 194402

<---------------------------------- Chemical Composition ---------------------------------->

(C)	(Mn)	(P)	(S)	(Si)	(Cr)	(Ni)	(Mo)	(Cu)	(Al)
.0300	1.6300	.0290	.0010	.3700	18.0000	8.0000	.4100	.2700	

<---------------------------------- Mechanical Composition ---------------------------------->

Tensile PSI: 90,000 Yield PSI: 45,000 Elongation: 52.1 Hardness as Shipped: 88RB

JK
3-10-09

==

Total Pounds: 4 A Page 1

BH

Bob Harley - Corporate Quality Manager

Version 9.2.11 - page 198

To the best of our knowledge, the aformentioned material conforms to all applicable standards

24

IMPERIAL STEEL TANK COMPANY

3234 WEST 31ST STREET

CHICAGO, ILLINOIS 60623

Welding Procedure Specification (WPS)

WPS No.: **WPS-02** Date: **1/18/1990** Rev.: **3** Date: **1/16/2004** Page: **1 of 2**

By: [illegible] Date Signed: 1-16-04

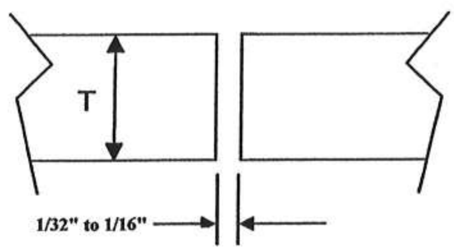
Supporting PQR's: **PQR-02**

Welding Process(es) / Type(s): **SMAW / Manual**

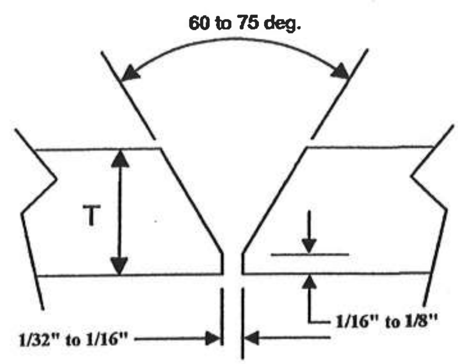
Joints (QW-402)

Joint Design: Groove and fillet welds

Backing: With or without backing Backing Material: CERAMIC or SIMILAR METAL



SQUARE GROOVE



SINGLE VEE GROOVE

Fillet Welds: All fillet sizes on all base metal thicknesses and all diameters.

Retainers: None

WELD JOINT DESCRIPTIONS SHOWN ARE NOT INCLUSIVE OF ALL THOSE FOUND ON A JOB. WELD JOINT DESIGNS REFERENCED IN AN ENGINEERING SPECIFICATION OR A DESIGN DRAWING SHALL TAKE PRECEDENCE OVER WELD JOINT DESIGNS SHOWN IN THIS WPS.

Base Metals (QW-403)

P-No.: 8 Group No.: 1 Thickness Range (in.): 0.0625 to 0.7500

to P-No.: 8 Group No.: 1

Minimum preheat must be maintained during thermal cutting, tacking, and welding operations.
Welds shall be cleaned between each pass. When completed, remove all slag and projections.

Filler Metals (QW-404)

Spec. No. (SFA): 5.4

AWS No. (Class): E308-17

F No.: 5 A No.: 8

Weld Metal Thickness Range: 0.0625 to 0.7500 in. No Pass Greater Than ½" Allowed

Flux Type: N/A

Flux Trade Name: N/A

Consumable Insert: N/A

Other:

C - WPS IX - A - WPW 5.2.2
Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

Welding Procedure Specification (WPS)

WPS No.: WPS-02 Date: 1/18/1990 Rev.: 3 Date: 1/16/2004 Page: 2 of 2

Positions (QW-405)

Position of Joint: Flat & Horizontal

Weld Progression: N/A

Postweld Heat Treatment (QW-407)

Type: No PWHT will be performed

Temperature Range: None °F

Time Range: None

Preheat (QW-406)

Preheat Temp. Min.: 50 °F

Interpass Temp. Max.: N/A °F

Preheat Maintenance: None

Gas (QW-408)

Gas Composition / Flow Rate

Shielding: N/A

Trailing: N/A

Backing: N/A

Electrical Characteristics (QW-409)

Current Type / Polarity: DCEP (reverse)

Tungsten Electrode Type and Size: N/A

Mode of Metal Transfer for GMAW: N/A

Max. Heat Input (J/in): None

Technique (QW-410)

String or Weave Bead: String and weave bead

Initial and Interpass Cleaning: With Stainless steel brush clean 2 inches (50mm) on both sides of weld joint

Method of Back Gouging: When required, grind until all defects are removed.

Oscillation: N/A

Contact Tube to Work Distance: N/A

Single or Multiple Passes (per side): Multipass

Single or Multiple Electrodes: N/A

Peening: None

Process Welding Parameters

Weld Layer(s) and/or Pass(es)	Process	Filler Metal		Current		Voltage Range	Travel Speed Range (in/min)
		Class	Diameter (in.)	Type / Polarity	Amperage Range		
Any	SMAW	E308-17	3/32	DCEP (reverse)	60-90	n/r	Var.
Any	SMAW	E308-17	1/8	DCEP (reverse)	80-120	n/r	Var.
Any	SMAW	E308-17	5/32	DCEP (reverse)	110-160	n/r	Var.
Any	SMAW	E308-17	3/16	DCEP (reverse)	155-210	n/r	Var.

C - WPS IX - A - WPW 5.2.2
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IMPERIAL STEEL TANK COMPANY
3234 WEST 31ST STREET
CHICAGO, ILLINOIS 60623

Procedure Qualification Record (PQR)

PQR No.: **PQR-02** WPS No.: **WPS-02** Date: **12/4/1980** Page: **1 of 2**

Welding Process(es) / Type(s): **SMAW / Manual**

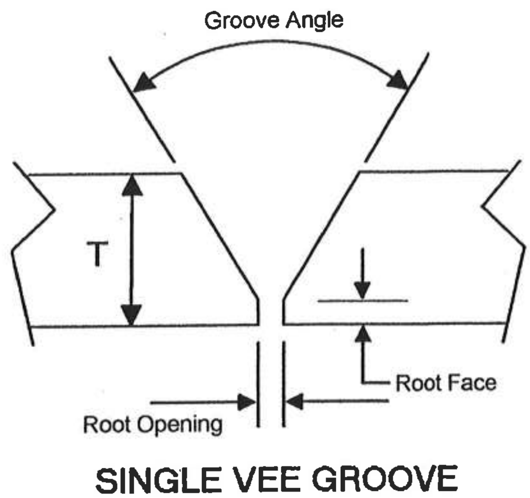
Joints (QW-402)

Weld Type: Groove weld
Single-V groove

Backing: Back-gouged and back welded

Root Opening: 1/16" in. Root Face: 1/8" in.

Groove Angle: 70 °



Base Metals (QW-403)

Material Spec., Type or Grade:
SA-240, Type 304 to SA-240, Type 304

P-No.: 8 Group No.: 1 to P-No.: 8 Group No.: 1

Thickness of Test Coupon (in.): 0.375

Filler Metals (QW-404)

SFA Specification: 5.4
AWS Classification: E308-17
Filler Metal F-No: 5
Weld Metal Analysis A-No: 8
Size of Filler Metal (in.): 1/8
Weld Deposit 't' (in.): 0.375
Pass Greater Than ½": No

Positions (QW-405)

Position of Joint: 2G - Horizontal
Weld Progression: N/A

Preheat (QW-406)

Preheat Temp.: 50 °F
Interpass Temp.: N/A °F

Postweld Heat Treatment (QW-407)

Type: No PWHT performed
Temperature: None °F
Time: None hr

Gas (QW-408)

Gas Composition / Flow Rate
Shielding: N/A
Trailing: N/A
Backing: N/A

Electrical Characteristics (QW-409)

Current / Polarity: DCEP (reverse)
Amps: 80 - 120
Volts: 32 - 36
Tungsten Type / Size: N/A
Heat Input: N/R

Technique (QW-410)

Travel Speed (in/min): MANUAL
String/Weave Bead: String and weave bead
Oscillation: N/A
Mult./Single Pass (per side): Multipass
Mult./Single Electrode: N/A

(1) INITIAL CLEANING - WIRE BRUSH / SOLVENT; INTERPASS CLEANING - WIRE BRUSH
SECOND SIDE - GRIND TO SOUND METAL BEFORE DEPOSIT WELDING; NO PEENING

C - PQR IX - A - WPW 5.2.2
Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

Procedure Qualification Record (PQR)

PQR No.: PQR-02

Tensile Test (QW-150)

Specimen No.	Width (in.)	Thickness (in.)	Area (in^2)	Ultimate Total Load (lb)	Ultimate Stress (PSI)	Failure Type and Location
#1	1.554	0.402	0.625	51500	82400	Base metal
#2	1.585	0.384	0.6086	51000	83800	Base metal

Guided Bend Test (QW-160)

Figure Number and Type	Result	Figure Number and Type	Result
QW-462.3(a) Face bend	Acceptable	QW-462.3(a) Root bend	Acceptable
QW-462.3(a) Face bend	Acceptable	QW-462.3(a) Root bend	Acceptable
None		None	

Welder's Name: Bruno Wolyniec ID: 22 Stamp: 22

PQR was done and welding of coupon was witnessed by: IMPERIAL STEEL TANK COMPANY

Tests Conducted By: Pittsburgh Testing Laboratory Test ID.: 7757

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Section IX of the ASME Code.

Reproduced By: Steven Williams 1-14-04 Engineer *

Steven Williams Date

* THIS PQR IS A REPRODUCTION OF THE ORIGINAL PQR CREATED IN 1990 BY CHRISTOPHER MATULAJTYS. COPIES OF THE ORIGINAL ARE AVAILABLE ON REQUEST.

1-14-04

C - PQR IX - A - WPW 5.2.2
Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

~~3234 WEST 31ST STREET~~

CHICAGO, ILLINOIS 60623

Welding Procedure Specification (WPS)

WPS No.: **WPS-03** Date: **12/18/1980** Rev.: **1** Date: **1/19/2004** Page: **1 of 2**

By: Date Signed: 1-19-04

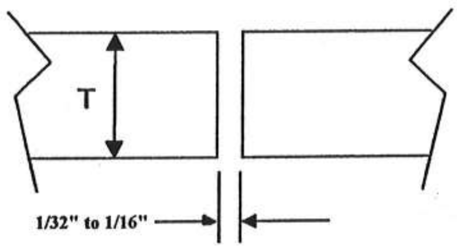
Supporting PQR's: **PQR-03**

Welding Process(es) / Type(s): **SMAW / Manual**

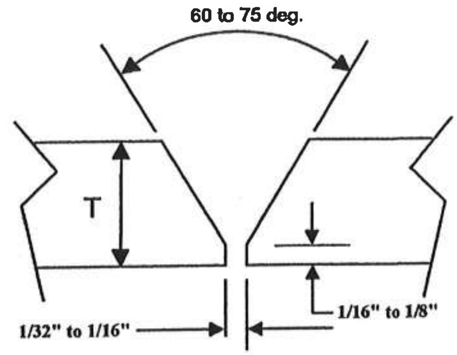
Joints (QW-402)

Joint Design: Groove and fillet welds

Backing: With or without backing Backing Material: Ceramic or Similar Metal



SQUARE GROOVE



SINGLE VEE GROOVE

Fillet Welds: All fillet sizes on all base metal thicknesses and all diameters.

Retainers: None

WELD JOINT DESCRIPTIONS SHOWN ARE NOT INCLUSIVE OF ALL THOSE FOUND ON A JOB. WELD JOINT DESIGNS REFERENCED IN AN ENGINEERING SPECIFICATION OR A DESIGN DRAWING SHALL TAKE PRECEDENCE OVER WELD JOINT DESIGNS SHOWN IN THIS WPS.

Base Metals (QW-403)

P-No.: 1 Group No.: 1 Thickness Range (in.): 0.0625 to 0.7500

to P-No.: 8 Group No.: 1

Minimum preheat must be maintained during thermal cutting, tacking, and welding operations.
Welds shall be cleaned between each pass. When completed, remove all slag and projections.

Filler Metals (QW-404)

Spec. No. (SFA): 5.4

AWS No. (Class): E309-16

F No.: 5 A No.: 8

Weld Metal Thickness Range: 0.0625 to 0.7500 in. No Pass Greater Than ½" Allowed

Flux Type: N/A

Flux Trade Name: N/A

Consumable Insert: N/A

Other:

IMPERIAL STEEL TANK COMPANY

Welding Procedure Specification (WPS)

WPS No.: WPS-03 Date: 12/18/1980 Rev.: 1 Date: 1/19/2004

Positions (QW-405)

Position of Joint: Flat & Horizontal

Weld Progression: N/A

Preheat (QW-406)

Preheat Temp. Min.: 50 °F

Interpass Temp. Max.: - °F

Preheat Maintenance: None

Postweld Heat Treatment (QW-407)

Type: No PWHT will be performed

Temperature Range: None °F

Time Range: None

Gas (QW-408)

Gas Composition / Flow Rate

Shielding: N/A

Trailing: N/A

Backing: N/A

Electrical Characteristics (QW-409)

Current Type / Polarity: DCEP (reverse)

Tungsten Electrode Type and Size: N/A

Mode of Metal Transfer for GMAW: N/A

Max. Heat Input (J/in): None

Technique (QW-410)

String or Weave Bead: String and weave bead

Initial and Interpass Cleaning: With wire brush clean 1 inch (25mm) on both sides of weld joint

Method of Back Gouging: When required, grind until all defects are removed.

Oscillation: N/A

Contact Tube to Work Distance: N/A

Single or Multiple Passes (per side): Multipass

Single or Multiple Electrodes: N/A

Peening: None

Process Welding Parameters

Weld Layer(s) and/or Pass(es)	Process	Filler Metal		Current		Voltage Range	Travel Speed Range (in/min)
		Class	Diameter (in.)	Type / Polarity	Amperage Range		
Any	SMAW	E309-16	3/32	DCEP (reverse)	60-90	n/r	Var.
Any	SMAW	E309-16	1/8	DCEP (reverse)	80-120	n/r	Var.
Any	SMAW	E309-16	5/32	DCEP (reverse)	110-160	n/r	Var.
Any	SMAW	E309-16	3/16	DCEP (reverse)	155-210	n/r	Var.

C - WPS IX - A - WPW 5.2.2
Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

3234 WEST 31ST STREET

CHICAGO, ILLINOIS 60623

Procedure Qualification Record (PQR)

PQR No.: PQR-03 WPS No.: WPS-03 Date: 12/4/1980 Page: 1 of 2

Welding Process(es) / Type(s): SMAW / Manual

Joints (QW-402)

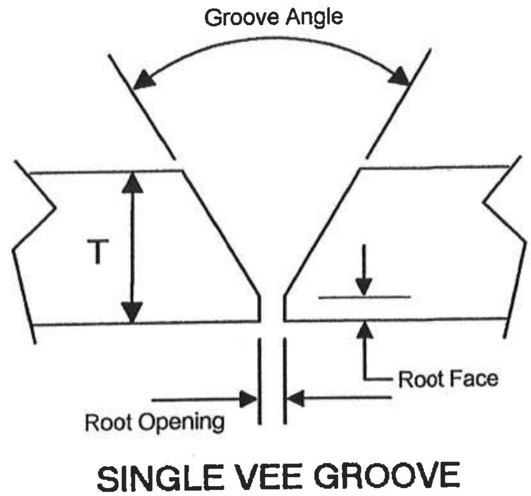
Weld Type: Groove weld

Single-V groove

Backing: Back-gouged and back welded

Root Opening: 1/16" in. Root Face: 1/8" in.

Groove Angle: 70 °



Base Metals (QW-403)

Material Spec., Type or Grade:

SA-285, Grade C to SA-240, Type 304

P-No.: 1 Group No.: 1 to P-No.: 8 Group No.: 1

Thickness of Test Coupon (in.): 0.375

Filler Metals (QW-404)

SFA Specification: 5.4

AWS Classification: E309-16

Filler Metal F-No: 5

Weld Metal Analysis A-No: 8

Size of Filler Metal (in.): 1/8

Weld Deposit 't' (in.): 0.375

Pass Greater Than ½": No

Positions (QW-405)

Position of Joint: 2G - Horizontal

Weld Progression: N/A

Preheat (QW-406)

Preheat Temp.: 50 °F

Interpass Temp.: °F

Postweld Heat Treatment (QW-407)

Type: No PWHT performed

Temperature: None °F

Time: None hr

Gas (QW-408)

Gas Composition / Flow Rate

Shielding: N/A

Trailing: N/A

Backing: N/A

Electrical Characteristics (QW-409)

Current / Polarity: DCEP (reverse)

Amps: 80 - 120

Volts:

Tungsten Type / Size: N/A

Heat Input: N/R

Technique (QW-410)

Travel Speed (in/min): MANUAL

String/Weave Bead: String and weave bead

Oscillation: N/A

Mult./Single Pass (per side): Multipass

Mult./Single Electrode: N/A

C - PQR IX - A - WPW 5.2.2

Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

Procedure Qualification Record (PQR)

PQR No.: PQR-03

Tensile Test (QW-150)

Specimen No.	Width (in.)	Thickness (in.)	Area (in^2)	Ultimate Total Load (lb)	Ultimate Stress (PSI)	Failure Type and Location
#1	1.48	0.380	0.5624	34500	61300	Base metal
#2	1.482	0.380	0.5632	35500	63000	Base metal

Guided Bend Test (QW-160)

Figure Number and Type	Result	Figure Number and Type	Result
QW-462.3(a) Face bend	Acceptable	QW-462.3(a) Root bend	Acceptable
QW-462.3(a) Face bend	Acceptable	QW-462.3(a) Root bend	Acceptable
None		None	

Welder's Name: Bruno Wolyniec ID: 22 Stamp: 22

PQR was done and welding of coupon was witnessed by: IMPERIAL STEEL TANK COMPANY

Tests Conducted By: Pittsburgh Testing Laboratory Test ID.: 7756

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Section IX of the ASME Code.

Reproduced By: Steven Williams 1-19-04 Engineer *

Steven Williams Date

* THIS PQR IS A REPRODUCTION OF THE ORIGINAL PQR CREATED IN 1980 BY CHRISTOPHER MATULAITYS. COPIES OF THE ORIGINAL ARE AVAILABLE ON REQUEST.

SEW

1/19/04

IMPERIAL STEEL TANK COMPANY

3234 WEST 31ST STREET

CHICAGO, ILLINOIS 60623

Welding Procedure Specification (WPS)

WPS No.: **WPS-28** Date: **5/30/1990** Rev.: **1** Date: **3/24/2004** Page: **1 of 2**

By: [illegible] Date Signed: 3-24-04

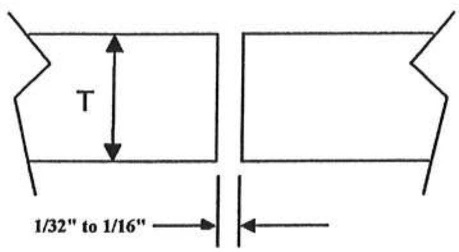
Supporting PQR's: **PQR-28**

Welding Process(es) / Type(s): **FCAW / Semiautomatic**

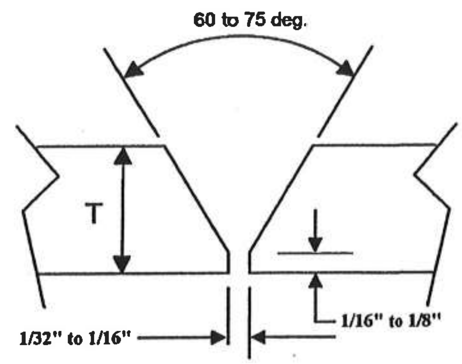
Joints (QW-402)

Joint Design: Groove and fillet welds

Backing: With or without backing Backing Material: Ceramic or Similar Metal



SQUARE GROOVE



SINGLE VEE GROOVE

Fillet Welds: All fillet sizes on all base metal thicknesses and all diameters.

Retainers: None

WELD JOINT DESCRIPTIONS SHOWN ARE NOT INCLUSIVE OF ALL THOSE FOUND ON A JOB. WELD JOINT DESIGNS REFERENCED IN AN ENGINEERING SPECIFICATION OR A DESIGN DRAWING SHALL TAKE PRECEDENCE OVER WELD JOINT DESIGNS SHOWN IN THIS WPS.

Base Metals (QW-403)

P-No.: 8 Group No.: 1 Thickness Range (in.): 0.0625 to 0.7500

to P-No.: 8 Group No.: 1

Minimum preheat must be maintained during thermal cutting, tacking, and welding operations.
Welds shall be cleaned between each pass. When completed, remove all slag and projections.

Filler Metals (QW-404)

Spec. No. (SFA): 5.22

AWS No. (Class): E308LT0-1

F No.: 6 A No.: 8

Weld Metal Thickness Range: 0.7500 in. maximum No Pass Greater Than ½" Allowed

Flux Type: N/A

Flux Trade Name: N/A

Consumable Insert: N/A

Other:

Product Form: Flux cored

Supplemental Filler Metal: NONE

C - WPS IX - A - WPW 5.2.2
Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

Welding Procedure Specification (WPS)

WPS No.: WPS-28 Date: 5/30/1990 Rev.: 1 Date: 3/24/2004 Page: 2 of 2

Positions (QW-405)

Position of Joint: All Positions

Weld Progression: Any

Preheat (QW-406)

Preheat Temp. Min.: 50 °F

Interpass Temp. Max.: N/A °F

Preheat Maintenance: None

Postweld Heat Treatment (QW-407)

Type: No PWHT will be performed

Temperature Range: None °F

Time Range: None

Gas (QW-408)

Gas Composition / Flow Rate

Shielding: 75% Argon, 25% CO2 / 23-48 CFH

Trailing: None

Backing: None

Electrical Characteristics (QW-409)

Current Type / Polarity: DCEP (reverse)

Tungsten Electrode Type and Size: N/A

Mode of Metal Transfer for GMAW: Spray arc

Max. Heat Input (J/in): None

Technique (QW-410)

String or Weave Bead: String and weave bead

Orifice or Gas Cup Size: 3/8" to 5/8"

Initial and Interpass Cleaning: With Stainless steel brush clean 2 inches (50mm) on both sides of weld joint

Method of Back Gouging: When required, grind until all defects are removed.

Oscillation: N/A

Contact Tube to Work Distance: 3/4(19mm)-1"(25mm).

Single or Multiple Passes (per side): Multipass

Single or Multiple Electrodes: N/A

Peening: None

Process Welding Parameters

Weld Layer(s) and/or Pass(es)	Process	Filler Metal		Current		Voltage Range	Travel Speed Range (in/min)
		Class	Diameter (in.)	Type / Polarity	Amperage Range		
Any	FCAW	E308LT0-1	0.035	DCEP (reverse)	120-200	19-24	Var.
Any	FCAW	E308LT0-1	0.045	DCEP (reverse)	150-225	22-26	Var.
Any	FCAW	E308LT0-1	1/16	DCEP (reverse)	175-275	25-28	Var.
Any	FCAW	E308LT0-1	5/64	DCEP (reverse)	200-400	26-32	Var.
Any	FCAW	E308LT0-1	3/32	DCEP (reverse)	300-500	26-34	Var.

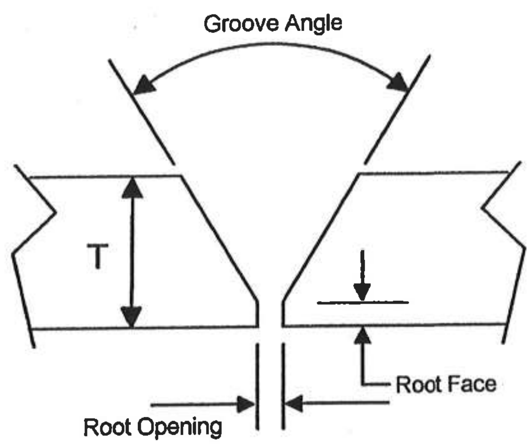
IMPERIAL STEEL TANK COMPANY
3234 WEST 31ST STREET
CHICAGO, ILLINOIS 60623
Procedure Qualification Record (PQR)

PQR No.: **PQR-28** WPS No.: **WPS-28** Date: **3/24/2004** Page: **1 of 2**

Welding Process(es) / Type(s): **FCAW / Semiautomatic**

Joints (QW-402)

Weld Type: Groove weld
Single-V groove
Backing: Back-gouged and back welded
Root Opening: 1/16" in. Root Face: 1/8" in.
Groove Angle: 70 °



SINGLE VEE GROOVE

Base Metals (QW-403)

Material Spec., Type or Grade:
SA-240, Type 304 to SA-240, Type 304
P-No.: 8 Group No.: 1 to P-No.: 8 Group No.: 1
Thickness of Test Coupon (in.): 0.375

Filler Metals (QW-404)

SFA Specification: 5.22
AWS Classification: E308LT0-1
Filler Metal F-No: 6
Weld Metal Analysis A-No: 8
Size of Filler Metal (in.): 0.045
Weld Deposit 't' (in.): 0.375
Pass Greater Than ½": No
Filler Metal Product Form: Flux cored
Supplemental Filler Metal: NONE

Positions (QW-405)

Position of Joint: 2G - Horizontal
Weld Progression: N/A

Preheat (QW-406)

Preheat Temp.: 50 °F
Interpass Temp.: N/A °F

Postweld Heat Treatment (QW-407)

Type: No PWHT performed
Temperature: None °F
Time: None hr

Gas (QW-408)

Gas Composition / Flow Rate
Shielding: 75% Argon, 25% CO2 / 25 - 40 CFH
Trailing: None
Backing: None

Electrical Characteristics (QW-409)

Current / Polarity: DCEP (reverse)
Amps: 235
Volts: 24
Tungsten Type / Size: N/A
Transfer Mode: Spray arc
Heat Input: N/R

Technique (QW-410)

Travel Speed (in/min): 12-18
String/Weave Bead: String and weave bead
Oscillation: N/A
Mult./Single Pass (per side): Multipass
Mult./Single Electrode: N/A

C - PQR IX - A - WPW 5.2.2
Form 2003 - Rev. 0

IMPERIAL STEEL TANK COMPANY

Procedure Qualification Record (PQR)

PQR No.: **PQR-28**

Tensile Test (QW-150)

Specimen No.	Width (in.)	Thickness (in.)	Area (in^2)	Ultimate Total Load (lb)	Ultimate Stress (PSI)	Failure Type and Location
28-T1	0.719	0.334	0.240	22100	92083	Ductile - WM
28-T2	0.738	0.352	0.259	24000	92664	Ductile - WM

Guided Bend Test (QW-160)

Figure Number and Type	Result	Figure Number and Type	Result
QW-462.2 Side bend	Acceptable	QW-462.2 Side bend	Acceptable
QW-462.2 Side bend	Acceptable	QW-462.2 Side bend	Acceptable
None		None	

Welder's Name: Rosa Sr, Felix ID: 1050 Stamp: 1050

PQR was done and welding of coupon was witnessed by: IMPERIAL STEEL TANK COMPANY

Tests Conducted By: CALUMET TESTING SERVICES Test ID.: 5100

We certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of Section IX of the ASME Code.

Prepared By: Steven Williams 8-24-04 Engineer

Steven Williams Date

C - PQR IX - A - WPW 5.2.2
Form 2003 - Rev. 0

Calumet Testing Services
1945 N. Griffith Blvd.
Griffith, Indiana 46319
(219) 923-9800—(708) 474-5860

X TENSILE TEST REPORT
X BEND TEST REPORT
___ HARDNESS TEST REPORT

CUSTOMER: Imperial Steel Tank Company JOB NO. 5100
SAMPLE PQR-28, WPS-28, WPQ1050-28
CODE ASME Sec. IX EDITION 2001/2003

TENSILE RESULTS:

Specimen No.	Width inch	Thickness inch	Area Sq. in.	Yield Load (lb.)	Max. load (lb.)	Yield Strength (psi)	Ultimate Strength (psi)
28-T1	0.719	0.334	0.240	N/A	22,100	N/A	92,083
28-T2	0.738	0.352	0.259	N/A	24,000	N/A	92,664

Specimen No.	ELONGATION (% inch)	Diameter (inch)	Character & Location of Fracture
28-T1	N/A	N/A	Ductile/Weld metal
28-T2	N/A	N/A	Ductile/Weld metal

BEND RESULTS: Figure No. QW-462.2

28-A Side Bend Acceptable
28-B Side Bend Acceptable
28-C Side Bend Acceptable
28-D Side Bend Acceptable

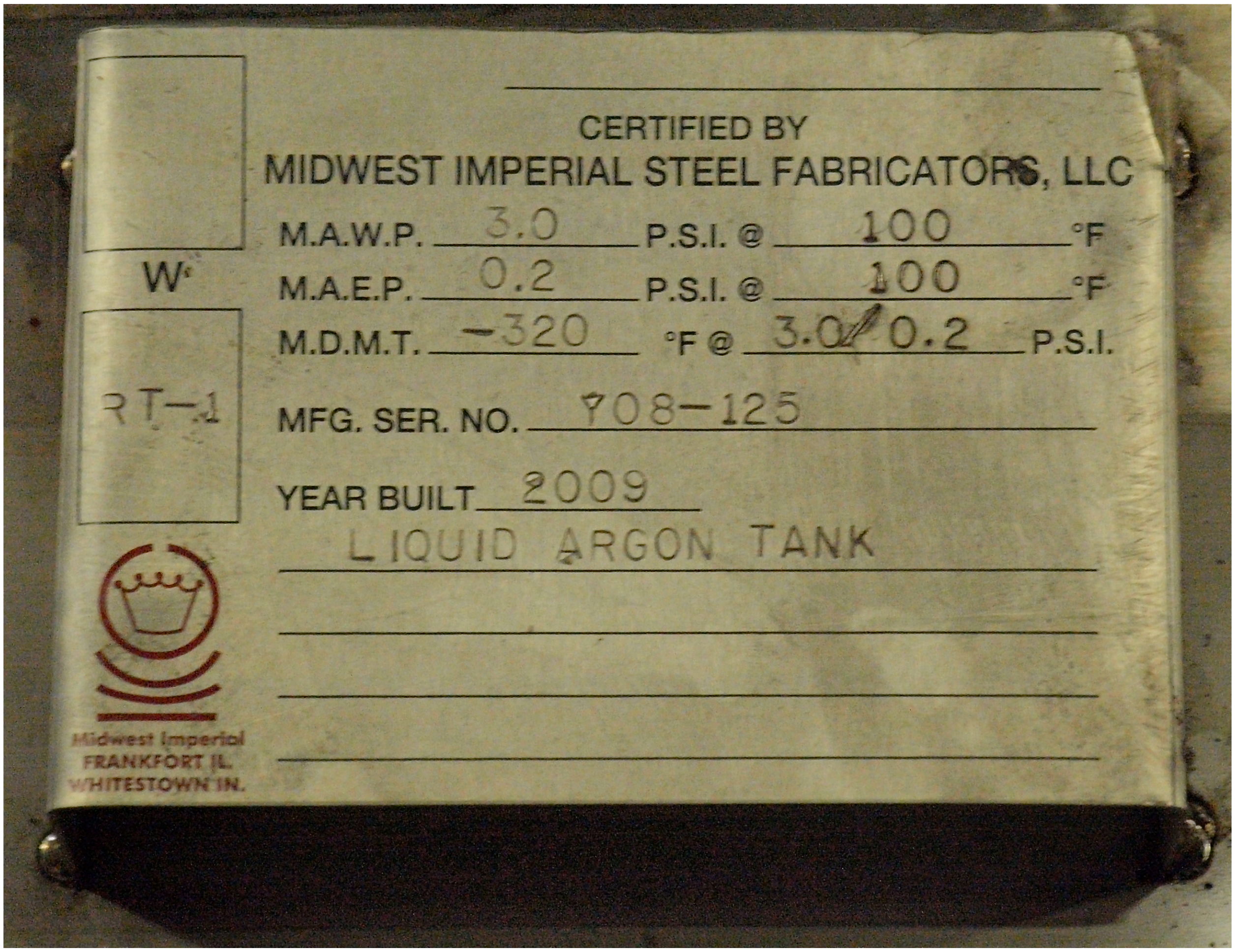
Root Bend N/A Root Bend N/A Face Bend N/A Face Bend N/A

HARDNESS RESULTS: N/A

John A. Korienek

March 24, 2004
Date

VII. C. Nameplate Photograph



Midwest Imperial

Established 1952 Leaders in ASME Pressure Vessel Construction

September 1, 2009

FERMI LAB
Kirk Road & Wilson Street
Batavia, IL 60510

SUBJECT: Liquid Argon Tank ME-444715, FERMI LAB P.O. 583306, MIFAB JobY08-125

Dear Sir,
We certify that the design, materials, fabrication and workmanship on the subject tank conforms to the requirements of API 620, Design and Construction of Large, Welded, Low-pressure Storage Tanks.

The subject tank was also inspected upon completion and pressure tested to a minimum test pressure of 3.75 psig. To the best of our knowledge the tank complies with the applicable sections of API 620.

Regards,

Steven Williams
Engineering Manager

400 South La Grange Road, Suite C, Frankfort, IL 60423 815.469.1072 815.469.1075 fax

VIII. TESTING

LAPD tank inspection

- Company: Midwest Imperial Steel Fabricators
- Contact: Sal Cerda
- Phone 815-469-1072
- address: 400 South LaGrange Road, Frankfort, IL 60423

The goal is to gather information to make sure the tank is built correctly. If there is a discrepancy or misunderstanding it may be discussed with Midwest, but any disputes will be settled through purchasing. The cleanliness inspection will be done later.

Safety

- Do not enter the tank
- Take ear protection with you
- Wear work boots, this is a steel fabrication shop
- Welding may be going on nearby
- Midwest should provide ladders and help with measurements. Don't climb anywhere insecure.

1. Check that the fittings and features on drawing Y08-125-1 are the right size. This includes all nozzles listed A through T. It is not necessary to measure their exact location on the tank unless they appear to be way off.
2. If the tank is on a level floor, check the fitting level in two directions.
3. Look inside for the mounting clips, probably not all are visible.
4. Make sure lifting lugs are installed at the top of the shell.
5. Measure the circumference of the tank within 18 inches of the bottom. 31' 6 1/2"
6. Measure the height from the highest flange to the bottom of the tank. — 153"
7. Look for scratches or other visible damage in general.
8. If flange faces are accessible, inspect for scratches or damage on sealing surfaces.
9. Make sure the vessel has eight anchor chairs. Measure the centerline distance between them. Check each one.
10. Take plenty of pictures, including the nameplate.
11. Ask for a copy of their test results detailed in section 5 of the specification
12. Notice the general cleanliness inside the tank.

INSPECTION BY JOHN VOIRIN
+ KOUROSH T. ON 6-5-09 JH

ACUREN
US Inspection Services (formerly)
1304 Sadlier Circle West Drive
Indianapolis, IN 46239
Phone: 317-890-9729
Fax: 317-890-890-8577

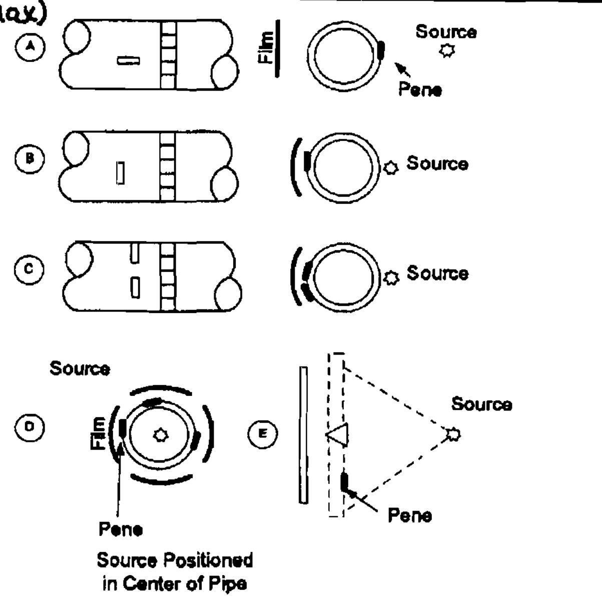
USI WO # 158317 Report Page 1 of 1
Date: 4-14-09
Customer: Midwest Metal Fabrication
6145 S. Indianapolis Rd.
Whitestown, IN
PO#: Y08125
Location: Same as above; Fab Shop
Description: Butt Welds
100% Insp ✓ Spot Insp. —

Serial # or Piece #
Customer WO # Y08125

Weld #	Film #	Acc.	Rej.	Code	Remarks
					Densitys (Min-Max)
L-1	0-1	✓		FA,P	2.46 - 3.22
	1-2	✓		UC	2.91 - 3.57
	2-3	✓		FA,P	2.60 - 3.10
	3-4	✓		P,S	2.62 - 3.10
	4-5	✓			2.60 - 3.10
	5-6	✓			2.50 - 3.00
	6-7	✓		P,S	2.62 - 2.95
	7-8	✓		P,UC,S	2.50 - 3.10
	8-9	✓		P	2.45 - 3.02
	9-10	✓		S,P	2.65 - 3.00
L-2	0-1	✓		S	2.85 - 3.20
	1-2	✓		S	2.83 - 3.00
	2-3	✓		S	2.63 - 3.22
	3-4	✓			3.02 - 3.25
L-3	0-1	✓			3.25 - 3.45
	1-2		X	P,IF	2.82 - 3.23
	2-3		X	P,IF	
	3-4	✓			
	4-5	✓		P	
L-4	0-1	✓		P	
	1-2	✓			
	2-3	✓		P	
	3-4	✓			
	4-5	✓			
L-5	0-1	~~✓~~	X	P,IF,S	
C-1	0-1	✓		P,S	
	1-2	✓			
	2-3	✓			
	3-4	✓			
	4-5		X	P	
	5-6	✓		P	
	6-7	✓		P	
	7-8	✓		P,S,UC	
	8-0	✓			

Technique Data

Insp. Specification: ASME V
RT Procedure: RT-1 Rev12/RT-1 Sup Rev10
Acceptance Stand.: ASME VIII Div I
RT Tech. used below: "D" & "E"



Material: SS / SS
Pipe Size: Various Wall Thk ±.250
Process: SMAW X GTAW (X) GMAW X
FCAW: SAW X Other
Source Isotope Ir192 Curies 74
Physical Size: .150" KVP/MA N/A
Exposure Time: 1m30sec SFD: 15"
Film/Object Inches: Contact
Geometric Unsharpness: ≤.020
Pene Type / Size: ASTM #12
Material: SS Placement SS
Shims: Material: SS Thickness .060
Marker/# Belt Pb Nos.
Film: Brand: AGFA Type: D4 (Read-Pack)
Size: 3½ x 17 Load: single
Emulsion(s) number::
Screens: Front: .002 Back: .002
Backing: —
Viewing Single: ✓ Double —
Density (Pen.) 2.18 - 3.72
Density (weld) min.max 2.10 - 3.80

P-Porosity
C-Crack
IF-Incomplete Fusion
IP-Incomplete Penetration
S-Surface
EI-Elongated Indication
SI-Slag Inclusion
BT-Burn Through
MT-Melt Through
UC-Undercut
FA-Film Artifact
TI-Tungsten Inclusion
CV-Root Concavity
CX-Root Convexity
OX-Oxidation
SK-Shrinkage

1 C.A. Faith III
Radiographer
2 C.A. Faith II C.A. Faith II
Interpreter
4-14-09

2

ACUREN
formerly US Inspection Services

1304 Sadlier Circle West Drive
Indianapolis, IN 46239
Phone: 317-890-9729
Fax: 317-890-890-8577

CF 4-15-09

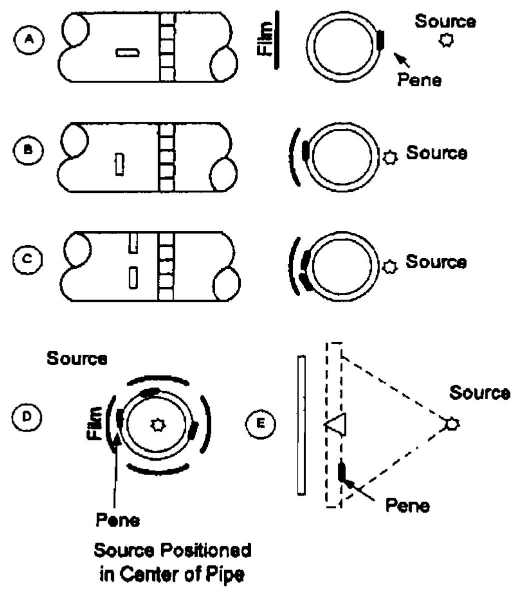
USI WO # 158317 Report Page 1 of 2
Date: 4-15-09
Customer: Midwest Metal Fabrication 6145 Indianapolis Rd. Whitestown, IN
PO#: Y08125
Location: Same As Above ; Fab Shop
Description: Butt Welds
100% Insp ✓ Spot Insp. —

Serial # or Piece # Various
Customer WO # Y08125

Weld #	Film #	Acc.	Rej.	Code	Remarks
L3R1	1-2		X	IF	
	2-3		X		
L6R1	0-1		X	P IF	
C1R1	4-5	✓		P	
L6	0-1		X	IF	

Technique Data

Insp. Specification ASME V
RT Procedure: RT-1 Rev 12/RT-1 Sup Rev 10
Acceptance Stand. ASME VIII Div I
RT Tech. used below: "D" + "E"



Material: SS/ SS
Pipe Size: Various/Plate Wall Thk. ≤.250
Process: SMAW X GTAW ⊗ GMAW X
FCAW: SAW X Other
Source Isotope Ir192 Curies 74
Physical Size: .159 KVP/MA N/A
Exposure Time: 1m 30sec SFD: 15"
Film/Object Inches: contact
Geometric Unsharpness: ≤.020
Pene Type / Size: ASTM #12
Material: SS Placement SS
Shims: Material: SS Thickness .060
Marker/# Belt Ob Nos
Film: Brand: AGFA Type: D4 (Ready
Size: Load: single Pack)
Emulsion(s) number::
Screens: Front: .002 Back: .002
Backing: —
Viewing Single: ✓ Double —
Density (Pen.) 2.0-4.0
Density (weld) min.max 2.0-4.0

P-Porosity
C-Crack
IF-Incomplete Fusion
IP-Incomplete Penetration
S-Surface
EI-Elongated Indication
SI-Slag Inclusion
BT-Burn Through
MT-Melt Through
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1 C.A. Faith II
Radiographer
2 C.A. Faith II C.A. Faith II
Interpreter
4-15-09

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ACUREN USInspection Services (formerly)

1304 Sadlier Circle West Drive
Indianapolis, IN 46239
Phone: 317-890-9729
Fax 317-890-890-8577

USI WO # 159887 Report Page 1 of 2
Date: 4-27-09
Customer: Midwest Imperial
6145 Indpls Rd.
Whitestown, IN
PO#: Y08125
Location: Same as above
Description: S/S butt welds
100% Insp ✓ Spot Insp. —

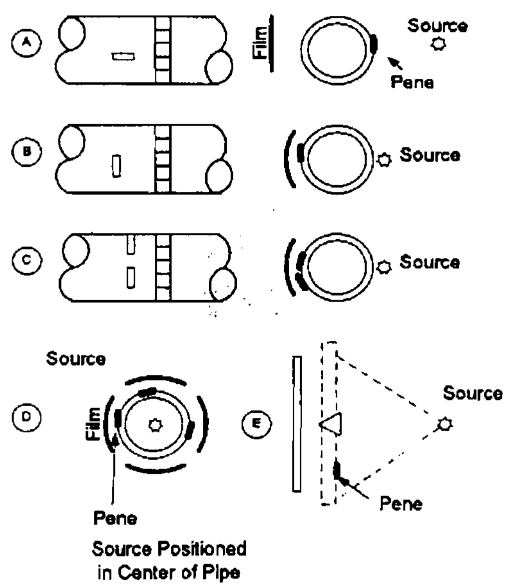
Serial # or Piece #
Customer WO #

Weld #	Film #	Acc.	Rej.	Code	Remarks
C-2	0-1	✓			
	1-2	✓			
	2-3	✓			
	3-4	✓			
	4-5	✓		P	
	5-6	✓			
	6-7	✓			
	7-8	✓			
	8-9	✓			
	9-10	✓			
	10-11	✓			
	11-12	✓			
	12-13	✓		FA	
	13-14	✓			
	14-15	✓			
	15-16	✓			
	16-17	✓			
	17-18	✓			
	18-19	✓			
	19-20	✓		FA	
	20-21	✓			
	21-22	✓			
	22-23	✓			
	23-24	✓			
	24-25	✓		P,	
	25-26	✓			
	26-27	✓			
	27-28	✓			
	28-0	✓			

P-Porosity
C-Crack
IF-Incomplete Fusion
IP-Incomplete Penetration
S-Surface
EI-Elongated Indication
SI-Slag Inclusion
BT-Burn Through
MT-Melt Through
UC-Undercut
FA-Film Artifact
TI-Tungsten Inclusion
CV-Root Concavity
CX-Root Convexity
OX-Oxidation
SK-Shrinkage

Technique Data

Insp. Specification: ASME V
RT Procedure: RT-1 Rev. 12/RT-1 Sup Rev. 10
Acceptance Stand. ASME VIII
RT Tech. used below: "D"



Material: S/S
Pipe Size: — Wall Thk. 3/16
Process: SMAW X GTAW X GMAW X
FCAW: SAW X Other
Source Isotope Ir 192 Curies 99
Physical Size: .160 KVP/MA —
Exposure Time: 7 min. SFD: 60"
Film/Object Inches: contact
Geometric Unsharpness: ≤ .020
Pene Type / Size: ASTM 12
Material: S/S Placement S/S
Shims: Material: S/S Thickness .060
Marker/# Belt Pb #'s
Film: Brand: AGFA Type: D5
Size: 4.5x17 Load: Single
Emulsion(s) number:: 6450605N
Screens: Front: .010 Back: .010
Backing: —
Viewing Single: ✓ Double —
Density (Pen.) 2.2-3.6
Density (weld) min.max 2.2-3.6

1 Radiographer
2 Interpreter Lev. II

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4

ACUREN USI formerly US Inspection Services

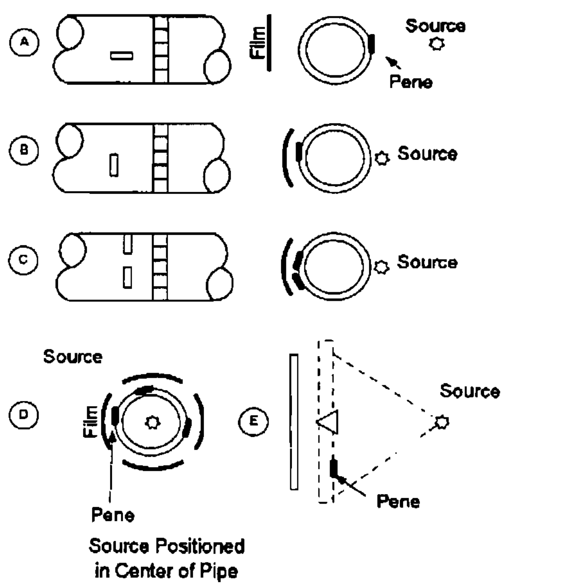
1304 Sadlier Circle West Drive
Indianapolis, IN 46239
Phone: 317-890-9729
Fax: 317-890-890-8577

USI WO # 159887 Report Page 2 of 2
Date: 4-27-09
Customer: Midwest Imperial
6145 Indpls Rd
Whitestown, IN
PO#: Y08125
Location: Same as above
Description: S/S butt welds
100% Insp ✓ Spot Insp. ✓

Serial # or Piece # ____
Customer WO # ____

Technique Data

Insp. Specification: ASME V
RT Procedure: RT-1 Rev. 12/RT-1 Sup Rev. 10
Acceptance Stand.: ASME VIII
RT Tech. used below: D & E



Weld #	Film #	Acc.	Rej.	Code	Remarks
C-3	0-1	✓			
	1-2	✓			
	2-3	✓			
	3-4	✓			
	4-5	✓			
	5-6	✓		P.	
	6-7	✓			
	7-8	✓			
	8-9	✓			
	9-10	✓			
	10-11	✓			
	11-12	✓			
	12-13	✓		P, S	
	13-14	✓			
	14-15	✓			
	15-16	✓			
	16-17	✓		P, S,	
	17-18	✓		S,	
	18-19	✓		P, S	
	19-20	✓		P.	
	20-21	✓			
	21-22	✓		S.	
	22-23	✓		P.	
	23-24	✓			
	24-25	✓			
	25-26	✓		S.	
	26-27	✓			
	27-28	✓			
	28-0	✓			
L-7	0-12	✓		P,	
	12-24	✓			
	24-36	✓			
	36-48	✓		P, FA	
	48-60	✓		P,	
L-8	0-12	✓			
	12-24	✓			
	24-36	✓			
	36-48	✓		P. FA	
	48-60	✓			
L-3 R2	1-2	✓			
	2-3	✓		P,	
L-5 R2	0-1	✓		P,	
L-6 R1	0-1	✓		P,	

Material: S/S
Pipe Size: —— Wall Thk. 3/16
Process: SMAW X GTAW X GMAW X
FCAW: SAW X Other
Source Isotope Ir 192 Curies 99
Physical Size: .160 KVP/MA ——
Exposure Time: 7min, 10min SFD: 60", 18"
Film/Object Inches: contact
Geometric Unsharpness: ≤.020
Pene Type / Size: ASTM 12
Material: S/S Placement S/S
Shims: Material: S/S Thickness .060
Marker/# Belt Pb #5
Film: Brand: AGFA Type: D5, D4
Size: 4.5x17x10 Load: Single
Emulsion(s) number:: 6450605N
Screens: Front: .010 Back: .010
Backing: ——
Viewing Single: ✓ Double ——
Density (Pen.) 2.2-3.6
Density (weld) min.max 2.2-3.6

P-Porosity
C-Crack
IF-Incomplete Fusion
IP-Incomplete Penetration
S-Surface
EI-Elongated Indication

SI-Slag Inclusion
BT-Burn Through
MT-Melt Through
UC-Undercut
FA-Film Artifact

TI-Tungsten Inclusion
CV-Root Concavity
CX-Root Convexity
OX-Oxidation
SK-Shrinkage

1 B. Hallam
Radiographer
2 B. Hallam Lev. II
Interpreter

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ACUREN formerly US Inspection Services
Acuren Inspection
1304 Sadlier Circle West Drive
Indianapolis, IN 46239
(317) 890-9729 Fax:(317)890-8577

VISUAL TECHNIQUE RECORD / INSPECTION REPORT

Form VT-01 Indy

Client: Midwest Metal	Work Order No.: 159887	Date: 4/28/09
Address/Job Location: Whitestown, IN	Job No.: Y08125	Specification: Client Info
Drawing No.: N/A		Procedure: OI-308 Rev-3
Part No.: See Below		Acceptance: Client Info. (No Cracks)
Type of Work: Routine ☐ New ☐ Repair ☐ Rework ☐		Technique No.: N/A

WELD IDENTIFICATION	WELD JOINT	WELD SIZE	SHOP / FIELD WELD	ACCEPT	REJECT	REMARKS
Chime Weld	T-Joint	1/4	shop	X		Preformed a Vac-box inspection test on the chime weld on tank # Y08125. I used 40 psi and 15 lbs of vacuum.
						Leak Detector Spray Batch # 061407

Defect Code: C - Crack; P - Porosity; NF - Non-fusion; LI - Linear Indication; S - Slag; LA - Lamination; UC - Undercut; Other (Specify):____

Weld Joint: B - Butt; SOL - Soc-o-let; F - Fillet; S - Socket; WOL - Weld-o-let

Inspector:____ Date:____ Client:____

Inspector: Tim Brummett Date: 4/28/09 Level II:____

The test report shall not be reproduced except in full, without the written approval of the laboratory; and the recording of false, fictitious, or fraudulent statements or entries on the certificate may be punished as a felony under federal law. Results are related only to items tested.

6

MIDWEST IMPERIAL

STEEL FABRICATORS, LLC
6145 S. INDIANAPOLIS ROAD
WHITESTOWN, INDIANA 46075
317-769-6489 fax 317-769-5461

May 11, 2009

Fermi National Laboratory
Batavia, Illinois

SUBJECT: Liquid Argon Tank PO 583306

This letter is certification that the subject tank was successfully hydrostatic tested.

The vessel was tested in the full condition at 4.5 psi for a period of 2 hours and no leaks were detected.

The test was conducted in the Midwest Imperial shop at 6145 S. Indianapolis Road, Whitestown, Indiana.

Sincerely,

Curt Hillenberg
Quality Control Manager

cc: Job file Y07-116

7

VIII. D. Empty Pneumatic Test – Internal Pressure

A pneumatic internal pressure test at 3.75 psig (1.25 x MAWP) was successfully completed on 7.22.11 and the test details follow this section title page. In addition, after the pressure test was complete the relief valve pressure sensing line was returned to its normal configuration and the tank was pressurized to 3 psig to verify that the relief valve is installed and operating properly (details attached).

Fermilab

Date: 7/20/11

EXHIBIT B
Pressure Testing Permit*

Type of Test: [ ]Hydrostatic [X] Pneumatic

Test Pressure 3.75 psig **Maximum Allowable Working Pressure** 3 psig
1.25 x 3 psig = 3.75 psig

Items to be Tested
LAPD tank – see attached notes.

Location of Test PC4 **Date and Time** TBD 7/22/11
9AM- 1PM

Hazards Involved
Stored energy of compressed gas.

Safety Precautions Taken
See attached notes.

Special Conditions or Requirements
See attached notes.

Qualified Person and Test Coordinator Terry Tope
Dept/Date PPD/MD/

Division/Section Safety Officer Bob Bushek PD/ESH
Dept/Date 7-22-11

Results
Tank held 3.75 psig for 1 hour w/no indicated drop after equalization. Max dial indicator shows .025" which is reasonable based on Analysis. [signature] 13394N2
See attached log

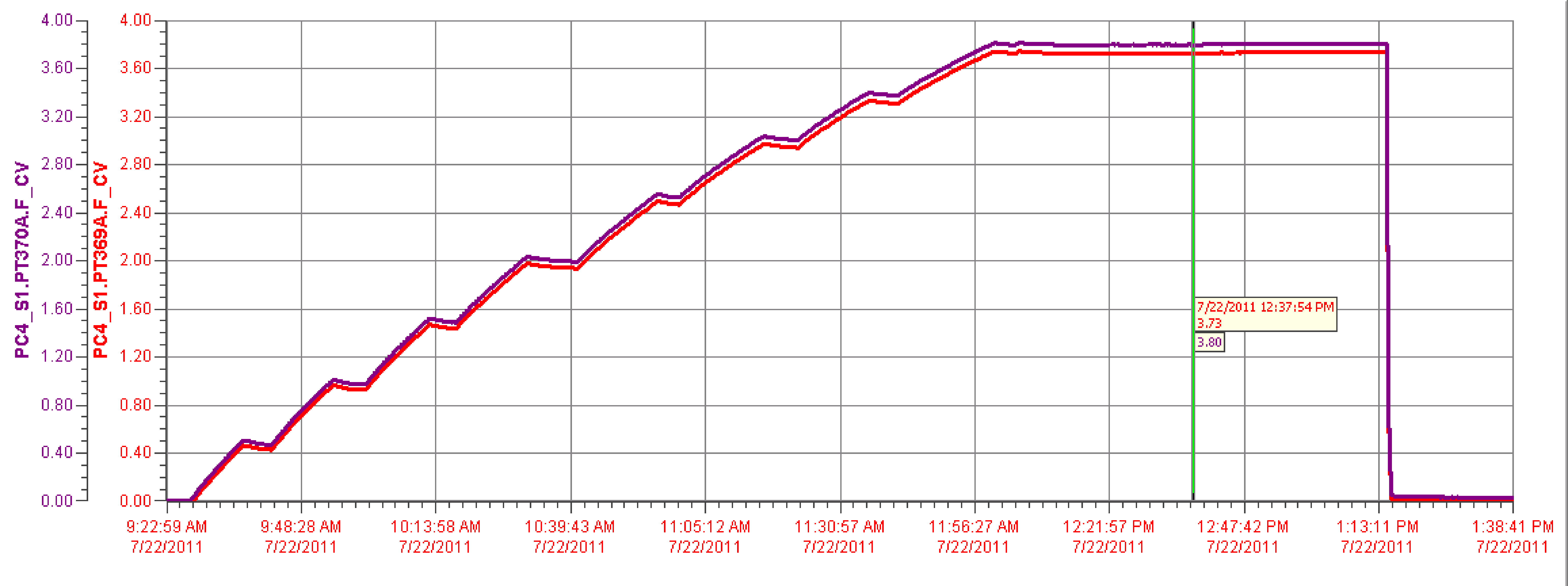
Witness [signature] **Dept/Date** PD/ESH 7-22-11
(Safety Officer or Designee)

* Must be signed by division/section safety officer prior to conducting test. It is the responsibility of the test coordinator to obtain signatures.

Nominal reading	time	PI-1 psia	PI-1 calculated psig	PI-2 psig	PT-369-Ar psig	PT-370-Ar psig	Dial indicator 1 thousandths	Dial indicator 2 thousandths	Dial indicator 3 thousandths	Dial indicator 4 thousandths
0	0914	14.35	0	-0.05	-0.01	0.021	0.494	0.497	0.499	0.200
0.5	0940	14.85	.5	0.45	0.463	0.423	0.494	0.495	0.498	0.200
1	0958	15.35	1.0	1.0	0.965	0.920	0.492	0.493	0.495	0.200
1.5	1017	15.85	1.5	1.5	1.483	1.456	0.490	0.491	0.491	0.200
2	1037	16.35	2.0	2.0	1.998	1.941	0.489	0.487	0.487	0.199
2.5	1100	16.85	2.5	2.5	2.525	2.466	0.488	0.483	0.485	0.198
3	1122	17.35	3.0	3.0	3.004	2.940	0.487	0.480	0.479	0.196
3.375	1140	17.70	3.35	3.3	3.375	3.309	0.486	0.478	0.477	[illegible]
3.75	1203	18.1	3.75	3.7	3.800	3.735	0.485	0.475	0.474	0.194
3.75@ 1 hour	1312	18.1	3.75	3.7	3.805	3.738	0.485	0.475	0.473	0.194
pressure released	1321	14.35	0	-.05	0.027	0.000	0.493	0.492	0.493	0.202

Nathan C. Bremer 22 July 2011

TERRY TOPE 13329W



Pen Name	Description	Value	Eng Units	High Over Range	Low Over Range
PC4_S1.PT369A.F_CV	LAPD tank vapor pressure transmi...	3.73	PSID	3.75	-0.05
PC4_S1.PT370A.F_CV	LAPD tank vapor pressure transmi...	3.80	PSID	3.81	-0.01

7/22/2011 7:38:41 AM | 6 Hours Ago | Current | 7/22/2011 1:38:41 PM

LAPD tank pressure test notes:

The LAPD tank pilot pressure relief valve (PSV-377-Ar) has a diaphragm which lifts the main valve seal. Under non-relieving conditions tank pressure is on both sides of the diaphragm. The tank side of the diaphragm has a smaller surface area than the relief side. Thus tank pressure on the relief side of the diaphragm holds the valve shut because the force is larger due to the larger surface area. When the tank pressure reaches the set point the relief pilot dumps the pressure on the relief side of the diaphragm and the tank pressure then lifts the seal and the valve relieves excess pressure in the tank.

For this pressure test PSV-377-Ar has a back pressure regulator (PRV-3) placed in its pressure sensing line (see Figure 1). PRV-3 is set to relieve at 3.8 psig such that if the tank pressure reaches 3.8 psig PRV-3 will open and send the pressure signal to the pilot valve on PSV-377-Ar which will open. This effectively raises the set point of PSV-377-Ar from 3 psig to 3.8 psig without tampering with internal the factory settings. PRV-4 sends the tank pressure signal to the pilot relief until about 2.8 psig to keep the valve closed by supplying the pressure to the relief side of the diaphragm required to keep the valve closed. Due to the unequal areas 2.8 psig on the relief side of the diaphragm is enough to keep the valve closed until the tank reaches 3.8 psig and PRV-3 sends the pressure signal to the pilot. CV-4 prevents communication between PRV-3 and PRV-4. MV-5 charges the relief side of the diaphragm until the cracking pressure of CV-4 is reached. This arrangement has been bench tested and documented by Bob Barger.

PCV-351-Ar is controlled by the PLC and will open at 3.9 psig if PSV-377-Ar fails to open. PCV-351-Ar can also be remotely opened at any time during the pressure test.

LAPD tank pressure test procedures

If at any time the tank appears unstable remotely vent the pressure by actuating PCV-375-Ar thru the computer.

Do not climb up on the tank platform at tank pressures greater than 1 psig.

If any rail car dial indicator indicates total movement exceeding 0.25 inches during the test remotely vent the tank thru PCV-351-Ar and stop the test.

1. Post “NO ENTRY PRESSURE TEST IN PROGRESS” signage at both PC4 entrance doors.
2. Only required test personnel may attend the pressure test. No other work may be carried out in the building during the test.

3. Make sure the valves required to be closed for the pressure test are closed per the highlighted flow schematic shown in Figure 1.
4. Position and zero the dial indicators as shown in Figure 2.
5. Make sure MV-350-Ar is open.
6. Actuate PCV-351-Ar from the iFix controls computer. Physically inspect the valve to make sure it actually moves from the closed to open position as expected.
7. Verify that PT-369-Ar and PT-370-Ar are indicating and archiving properly.
8. Close MV-330-Ar.
9. Connect the output of the "Remote Source Feed & Vent Controls" to MV-330-Ar.
10. Open MV-5 which is the bypass around CV-4 for the start of the pressure test.
11. Isolate the tank from its sintered metal atmospheric breather assembly.
12. Pressurize the system up to MV-350-Ar to ensure that the pressure supply is functioning properly.
13. Record the starting pressures indicated by PI-1 and PI-2 and the dial indicator values.
14. Open MV-350-Ar and pressurize the tank to 0.50 psig as indicated by PI-1 and then close MV-1.
15. Verify that PT-369-Ar and PT-370-Ar are in reasonable agreement with PI-1 and PI-2.
16. Take readings from the 4 dial indicators.
17. Hold this pressure for 10 minutes. If there is no observable pressure drop continue to next step.
18. Open MV-1 and pressurize the tank to 1.00 psig as indicated by PI-1 and then close MV-1.
19. Take readings from the 4 dial indicators.
20. Hold this pressure for 10 minutes. If there is no observable pressure drop close MV-5 and continue to next step.
21. After this step do not climb up on the tank platform without lowering the pressure to 1 psig or lower by using PCV-351-Ar or other remove means.
22. Open MV-1 and pressurize the tank to 1.50 psig as indicated by PI-1 and then close MV-1.
23. Take readings from the 4 dial indicators.
24. Hold this pressure for 10 minutes. If there is no observable pressure drop continue to next step.
25. Open MV-1 and pressurize the tank to 2.00 psig as indicated by PI-1 and then close MV-1.
26. Take readings from the 4 dial indicators.
27. Hold this pressure for 10 minutes. If there is no observable pressure drop continue to next step.
28. Change the breathable air supply bottle to ensure enough gas is available to complete the test.

29. Open MV-1 and pressurize the tank to 2.50 psig as indicated by PI-1 and then close MV-1.
30. Take readings from the 4 dial indicators.
31. Hold this pressure for 10 minutes. If there is no observable pressure drop continue to next step.
32. Open MV-1 and pressurize the tank to 3.00 psig as indicated by PI-1 and then close MV-1.
33. Take readings from the 4 dial indicators.
34. Hold this pressure for 10 minutes. If there is no observable pressure drop continue to next step.
35. Open MV-1 and pressurize the tank to 3.375 psig as indicated by PI-1 and then close MV-1.
36. Take readings from the 4 dial indicators.
37. Hold this pressure for 10 minutes. If there is no observable pressure drop continue to next step.
38. Open MV-1 and pressurize the tank to 3.75 psig as indicated by PI-1 and then close MV-1.
39. Take readings from the 4 dial indicators.
40. Hold this pressure for 1 hour.
41. Take readings from the 4 dial indicators.
42. Vent tank thru PCV-351-Ar and reduce tank pressure to ambient.
43. Take readings from the 4 dial indicators.
44. Open the valve that isolates the sintered metal atmospheric breather. Lock the valve open.

After the pressure test PSV-377-Ar must be restored to its normal configuration by directly connecting the pressure sensing line. The valve should then be tested in this configuration by pressurizing the tank until the valve begins to relieve at 3 psig.

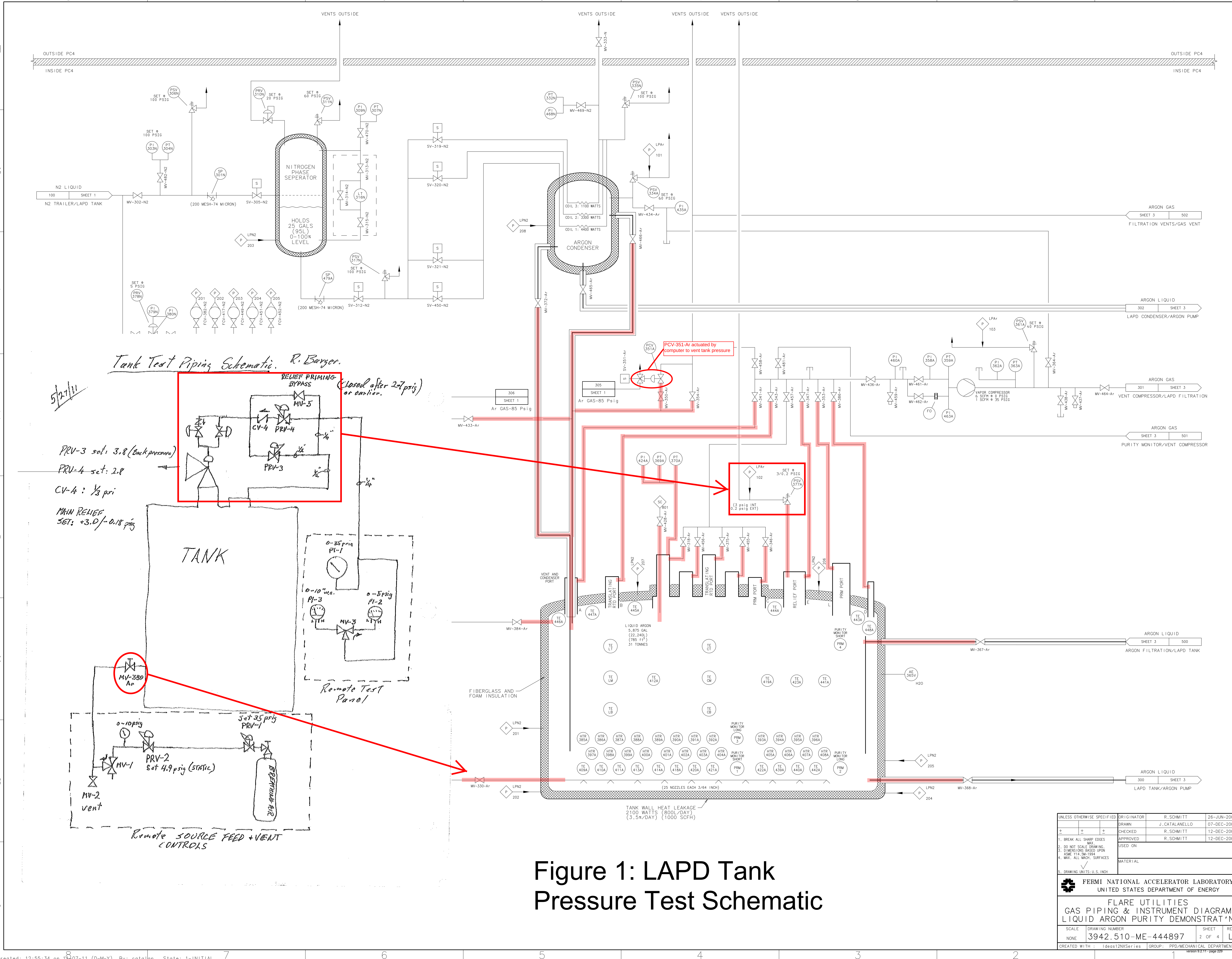


Figure 1: LAPD Tank Pressure Test Schematic

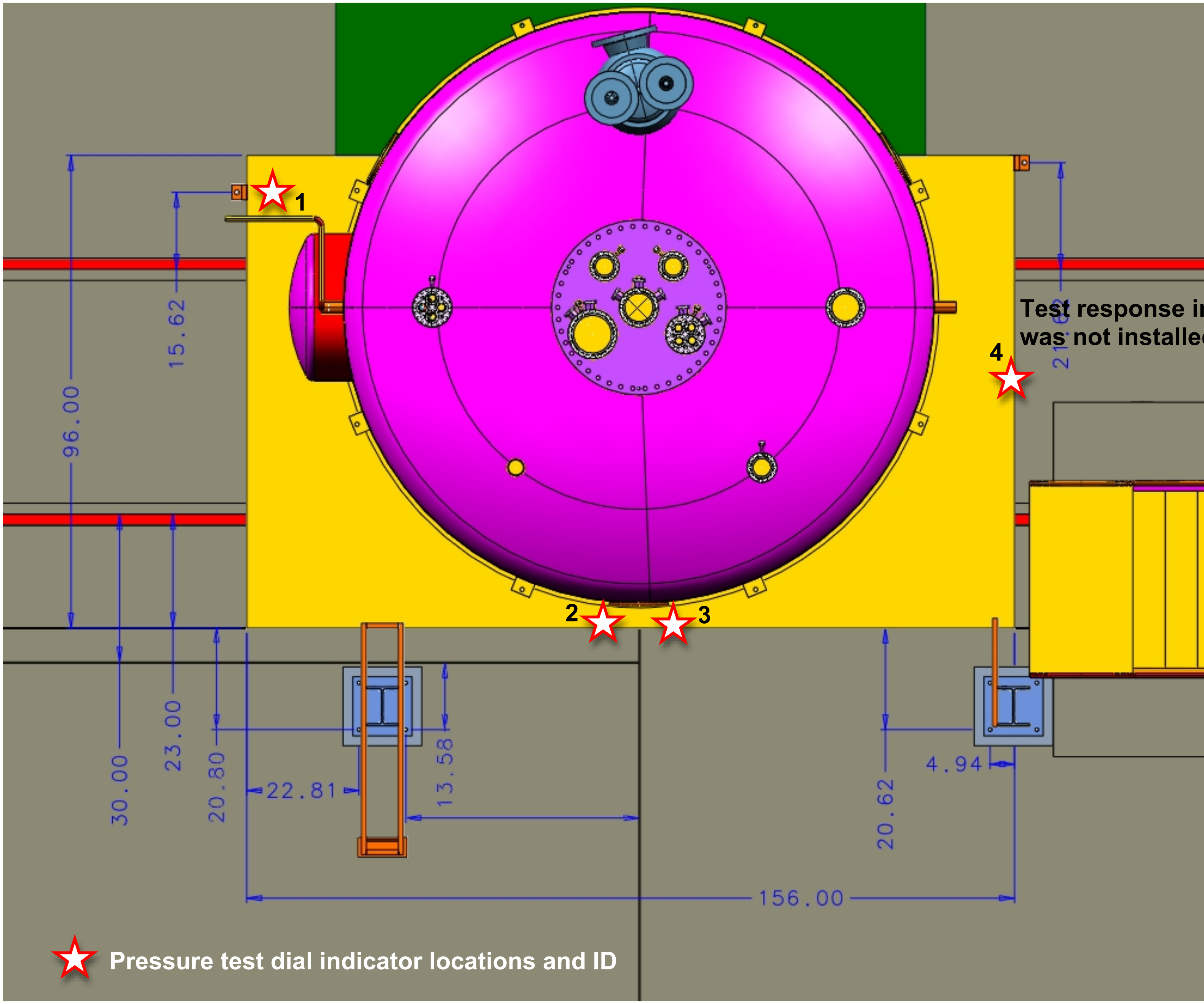
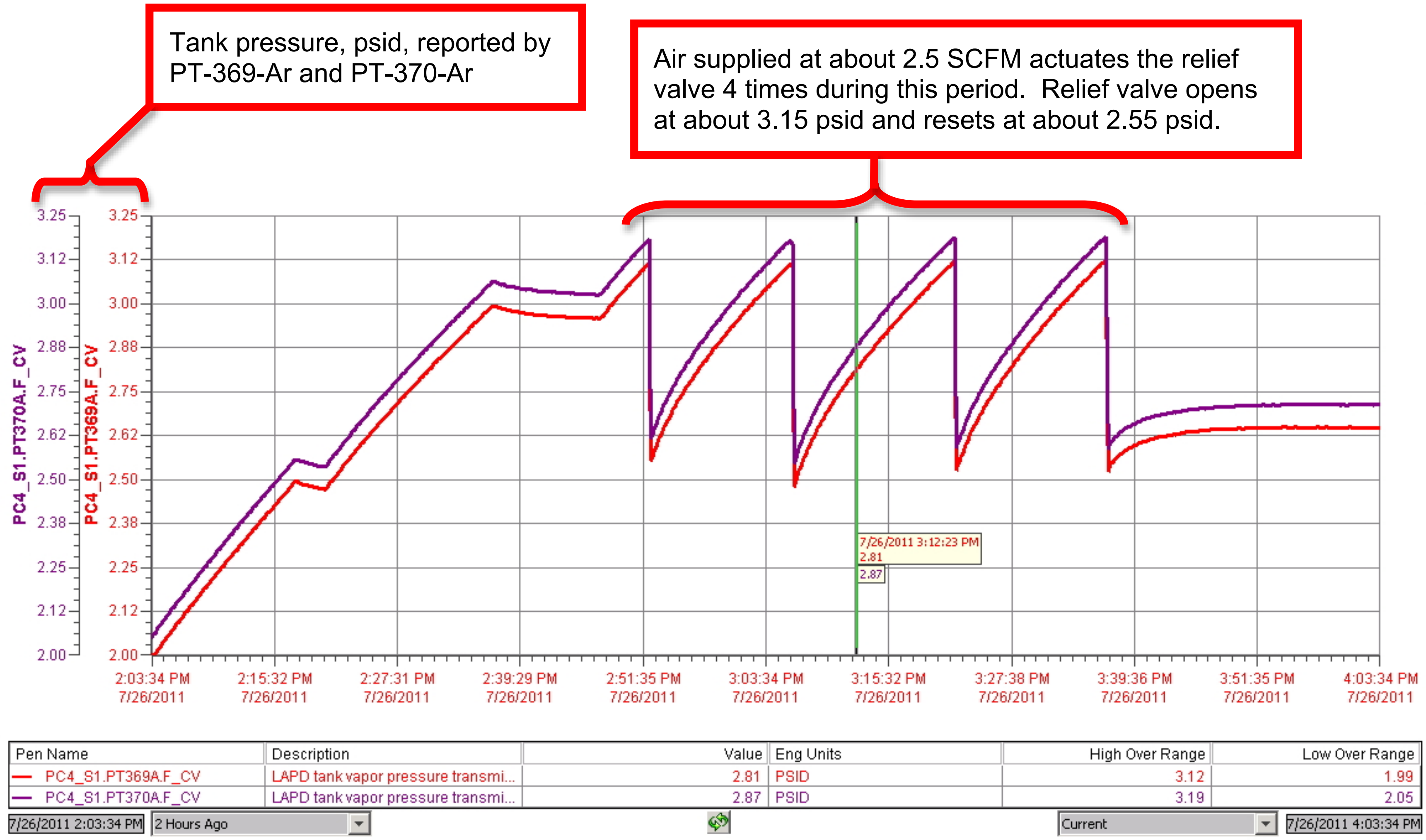


Figure 2: LAPD tank pressure test rail car dial indicator positions.



Test of the LAPD tank primary relief valve PSV-377-Ar installed on the tank in the normal operating configuration.

VIII. E. Empty Pneumatic Test – External Pressure

A pneumatic external pressure test at ~0.2 psid was successfully completed on 8.8.11 and the test details follow this section title page. A vacuum pump reduced the pressure inside the tank until the pilot relief valve opened to allow ambient air into the tank.

Fermilab

Date: 8/3/11

EXHIBIT B
Pressure Testing Permit*

Type of Test: [ ]Hydrostatic [X] Pneumatic **(external)**

Test Pressure 0.2 psid **Maximum Allowable Working Pressure** 0.2 psid

Notes: Tank nameplate external pressure rating is 0.2 psid. Analysis shows MAWP is 0.23 psid per ASME DIV 1 and 0.33 psid per ASME Div 2 .

Items to be Tested
LAPD tank – see attached notes.

Location of Test PC4 **Date and Time** TBD 1:30 8.8.11

Hazards Involved
Stored energy of compressed gas.

Safety Precautions Taken
Operation of the tank relief valve (PSV-377-Ar) has been bench tested for vacuum relief by Bob Barger in the PAB calibration shop.

Special Conditions or Requirements
Follow the attached procedure.

Qualified Person and Test Coordinator Terry Tope
Dept/Date PPD/MD/

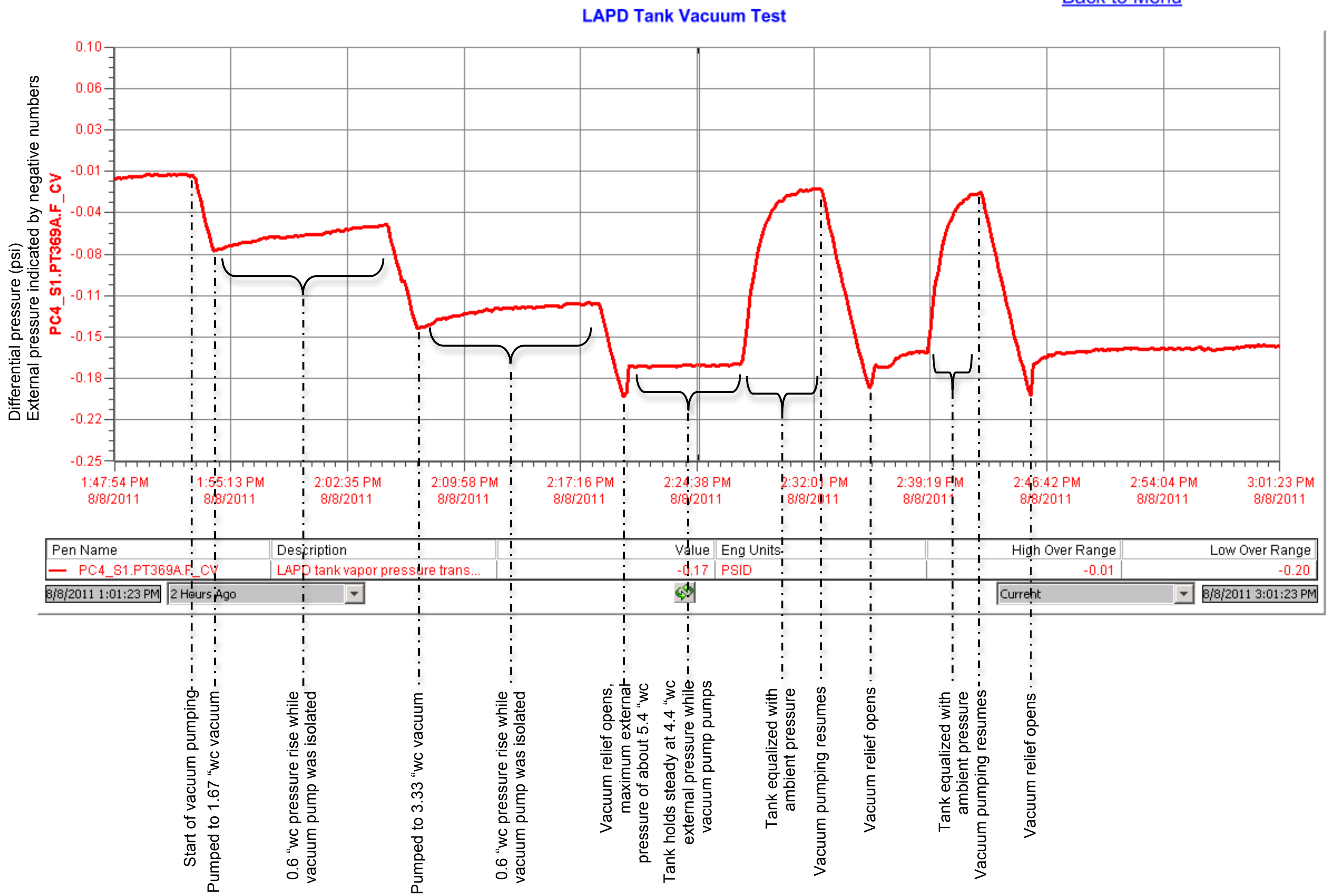
Division/Section Safety Officer PD/ES+H Eric McHugh
Dept/Date 8.8.11

Results
Relief opened for vacuum at ~5" wc and tank stayed at ~4" wc while vacuum pump pumped on tank. Terry Tope Actuated 2 more times with same result - see attached plot [signature]

Witness [signature] 13747N Dept/Date PD/ES&H 8.8.11
(Safety Officer or Designee)

* Must be signed by division/section safety officer prior to conducting test. It is the responsibility of the test coordinator to obtain signatures.

Back to Menu



The above plot shows the external pressure test of the LAPD tank as recorded by PT-369-Ar. The vacuum relief was actuated 3 times. During the 1st actuation a vacuum pump pumped on the tank for several minutes. During this period the relief valve held the tank at about 4.4 inches of water external pressure.

LAPD tank vacuum test

Date and time of test 8.8.2011 1:30 PM

Test personnel T. Tope, W. Bremer, R. Davis Witness E. Mchugh

Tank flange to floor reading before test (inches) 192" 10" CF to tank bottom

Nominal pressure " of H2O	Nominal pressure psid	time	PI-3 " of H2O	PI-1 psia	PI-1 psid	PI-487-Ar psia	PI-487-Ar psid
0	0	1332	0	14.3	0	14.25	0
1.67	0.060	1354	1.6	14.2	-0.10	14.2	-0.05
ten minute	rest	1404	1.0	14.25	-0.05	14.2	-0.05
3.33	0.120	1407	3.4	14.15	-0.15	14.1	-0.15
Ten minute	rest	1417	3.0	14.15	-0.15	14.15	-0.10
5	0.181						
actuated	at	approximately		5.2 inches	of H_2O		
pressure	then	stayed at		4.4 inches	of H_2O	with	pump
running.							
Next	Morning	9 Aug 2011					
		0722	4.0	14.1	-0.2	14.1	-0.25

Tank flange to floor reading after test (inches) 191 5/8

191 13/16 measured after internal pressurization.

version 8.3.11 - Terry Tope

LAPD tank vacuum test notes:

The LAPD tank pilot pressure relief valve (PSV-377-Ar) has an internal pressure set point of 3 psig and an external pressure set point of 0.18 psig. This test will reduce the pressure inside the LAPD tank until the vacuum relief opens and demonstrates its effectiveness for vacuum relief.

At no time during the test should the external pressure indicated by PI-3 exceed 6 inches of water. Nor should it exceed a 0.21 psi drop from the starting pressure indicated by PI-1 and PI-487-Ar. The vacuum source should be isolated if the external pressure exceeds these values.

LAPD tank pressure test procedures

1. Remove one of the spare 6 inch blank off conflat flanges on the large center tank flange. Measure the distance from the sealing surface of the conflat to the tank floor using a clean tape measure. Mark the perimeter location of the measurement on the conflat flange.
2. Insert a new copper seal and close the conflat flange.
3. Make sure the valves required to be closed for the pressure test are closed per the highlighted flow schematic shown in Figure 1.
4. Connect dry vacuum pump with a pirani gauge (PE-6), an isolation valve suitable for throttling (MV-5), and a vent valve (MV-7) to MV-330-Ar as shown in Figure 1.
5. Make sure MV-330-Ar is closed.
6. Connect the “remote test panel” to a spare VCR-4 fitting on the tank center flange using ¼” black poly for the tubing run from the floor to the top of the tank. Turn 3-way valve MV-3 towards PI-3 which is a 0-10 inches of water range pressure gauge.
7. Evacuate the piping up to MV-330-Ar to confirm that the vacuum pump is working properly. A pressure of 100 microns as indicated by PE-6 should be easily attainable.
8. Close MV-5.
9. Open MV-7 and bleed up the vacuum pumping line.
10. Close MV-7.
11. Close MV-483-Ar which isolates the sintered metal tank breather.
12. Open MV-330-Ar.
13. Note the “zero” readings for PI-3, PI-1, and PI-487-Ar. Add 0.21 psi to the absolute pressure readings of PI-1 and PI-487-Ar. This value should not be exceeded during the test.
14. Very slowly open MV-5 and pump the tank to an external pressure of 1.67 inches of water as indicated by PI-3. Observe PI-1 simultaneously to ensure PI-3 is indicating properly.
15. Close MV-5 and wait 10 minutes to observe any pressure rise. Log the PI-1, PI-3, PI-487-Ar values.

16. Very slowly open MV-5 and pump the tank to an external pressure of 3.33 inches of water as indicated by PI-3. Log the PI-1, PI-3, PI-487-Ar values.
17. Close MV-5 and wait 10 minutes to observe any pressure rise.
18. Very slowly open MV-5 and pump the tank to an external pressure of about 5 inches of water as indicated by PI-3. Slowly increase the external pressure beyond 5 inches of water until PSV-377-Ar opens.
19. Once it is verified that the vacuum relief is functional, fully open MV-5 to show that the relief valve can handle the full capacity of the vacuum pump.
20. Log the details of the relieving pressure.
21. Close MV-5. Open MV-7 and bleed up the tank.
22. The external pressure test is now complete.
23. Using the methods outlined in the previous steps actuate the relief valve for external pressure and note the reset characteristics. Do this 3 times.
24. Open the valve that isolates the sintered metal atmospheric breather. Lock the valve open.
25. Remove the spare 6 inch blank off conflat flange previously measured at. Measure the distance from the sealing surface of the conflat to the tank floor using a clean tape. Measure at the previously marked perimeter location.
26. Insert a new seal and close the conflat flange.

Figure 1: Flow schematic for LAPD tank vacuum test.

IX. Tank Filling Procedure

The current version of the tank filling procedure can be found here:

http://lartpc-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=553